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THE GEOLOGY OF THE OIL FIELDS OF BURMA[1]

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ABSTRACT

The oil fields of Burma occur as a long line from north to south near the center of the synclinal trough of Tertiary rocks which forms the central region of the country. The main fields are also puckers in the main trough. The region of Tertiary rocks is an old sea-gulf, bounded on the east by the Shan Plateau massif and on the west by the crestal rocks of the Arakan Yomas, which has gradually been filled up, mainly by river-borne sediments from the north. The oil appears to be found in the beds in which it was formed. The oil-bearing beds were laid down on the seaward side of the delta. Consequently the oil-bearing horizons follow the necessary conditions which, generally speaking, migrated gradually southward during the Tertiary period, though the southern course was interrupted at intervals. It is urged that a definite concentration of salts in the water is an essential condition for the formation of oil. Such a concentration may be attained either (*a*) on the seaward side of a delta, or (*b*) in a land-locked lagoon or lake. Probably the chemical nature of the salts varies greatly in different oil regions. A brief description of each of the fields is given and the change in the oil-bearing horizons illustrated by diagrammatic sections. The principal fields, from north to south, are Indaw, Yenangyat-Singu, Yenangyaung, Minbu (three small fields), Padaukpin, and Yenanma. The first and last two are comparatively recent discoveries. The largest producer has long been Yenangyaung which has yielded 3,000,000,000 gallons since 1900 from an area of a little more than one square mile. Singu has the largest reserves and is likely to take first place as a producer in the near future. All fields have been carefully and scientifically developed with the result that the total annual output of approximately 275,000,000 gallons during the past years will probably be maintained many years to come. The discovery of important new fields is unlikely.

INTRODUCTION

The present paper is intended to give a summary of the present state of knowledge concerning the geology and natural conditions affecting the Burmese oil fields. It is now nearly fifteen years since the publication of E. H. Pascoe's well-known memoir, and progress in the meantime has been considerable, thanks especially to the work of Bredenburg, Cotter, and Murray Stuart. Also it is hoped that this review of field conditions over one well-marked region may afford at least some useful contribution toward that most elusive of problems, the origin of oil.

[1] Presented before the Association at the Tulsa meeting, March 26, 1927.

[2] Sir Ernest Cassel reader in economic geography in the University of London. Introduced by Sidney Powers.

This paper is based very largely on one recently read before the Institution of Petroleum Technologists, London, and entitled "The Conditions Governing the Occurrence of Oil in Burma." Readers are referred to that paper for further details on the use which has been made of paleontology in Burma as well as for a summary of the present state of knowledge of the stratigraphy and paleontology of Burma. The writer is indebted to the Institution of Petroleum Technologists and also to the editor of the Geological Magazine (London) for permission to incorporate diagrams and matter already published.

Many of the investigations on which this paper is based were carried out while the writer was in the service of the Indo-Burma Petroleum Co. Ltd., and he is indebted to their managing agents, Steel Bros. & Co. Ltd., for permission to pub-

TABLE I

BURMA: PRODUCTION OF PETROLEUM (IN MILLIONS OF GALLONS)*

Year	Whole of India	Burma
1909	233,678,087	230,396,617
1910	214,829,647	211,507,903
1911	225,792,094	222,225,531
1912	249,083,518	245,335,209
1913	277,555,225	272,865,397
1914	259,342,710	254,652,963
1915	287,093,576	282,291,932
1916	297,189,787	291,769,083
1917	282,759,523	272,795,191
1918	286,585,011	274,834,556
1919	305,749,138	293,846,129
1920	293,116,834	279,707,170
1921	305,683,227	296,092,057
1922	298,504,125	281,759,169
1923	294,215,053	271,405,947
1924	294,571,692	270,213,003
1925	289,606,542	262,828,930

* 249 gallons = 1 metric ton.

lish this summary. The work has been supplemented by surveys carried out in 1920 for The Yomah Oil Co. Ltd., and, during the last three years, by research carried out under the auspices of the University of Rangoon.

THE PETROLEUM PRODUCTION OF BURMA

Although very distinct from the remainder of India, Burma is one of the British provinces of the Indian Empire. Statistics relating to the production of India therefore include Burma, and the same statement is true of the foreign trade of India.

The most important mineral product of India is, at present, coal. But ranking second in value is mineral oil, and the bulk of India's total comes from Burma. There are, it is true, small oil fields in Assam worked by the Burmah Oil Co. Ltd., and the Khaur field in the Punjab worked by the Attock Oil Co. Ltd., but the figures here given (Table I) show the predominating importance of Burma's share.

The figures also illustrate the remarkable steadiness in production for many years in succession. It will be seen later that the various fields have not always contributed in the same proportions. When production from one has dropped, another has been steadily developed to maintain output. This policy is still being maintained. As long ago as 1908 agreements were reached between the various oil companies concerned and the government of Burma (which is now regularly represented by the Warden of the oil fields) to prevent wasteful competition.[1]

Owing to the rapid increase in world production of oil, India's share has shown a steady percentage decrease. In 1912 India's total represented 2.09 per cent of the world's supply; in 1925 and 1926 it had sunk to less than 0.8 per cent.

AN OUTLINE OF THE GEOLOGY OF BURMA

The general geology of Burma is relatively simple and controls the topography to such a marked extent that the natural geographical and geological units in the country closely correspond.

The country may be divided into four parts:

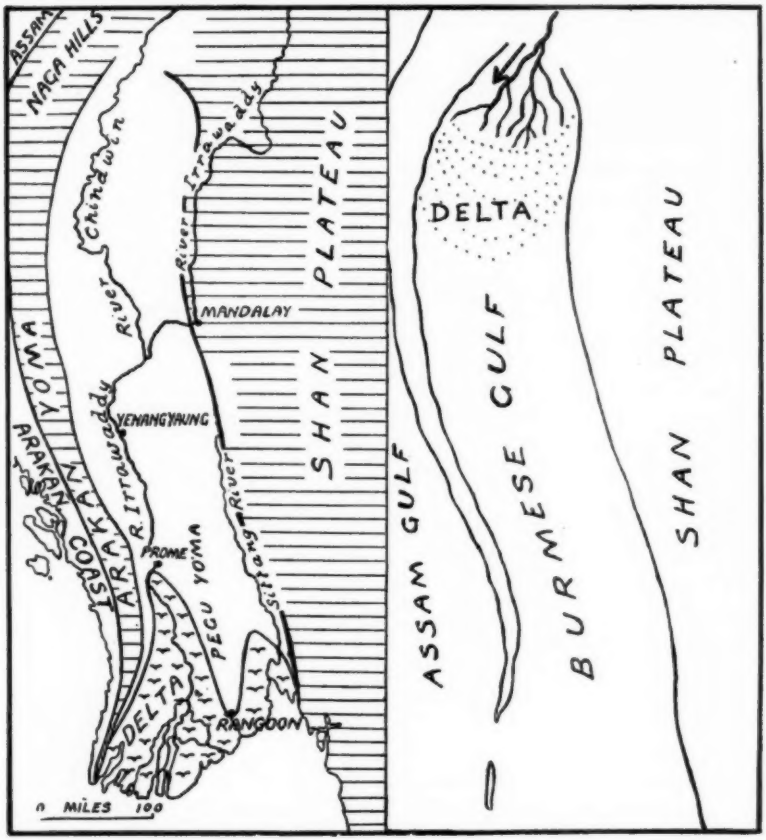
1. *The Eastern massif of old rocks.*—The whole of the east of the country, including the Shan States and Tenasserim, consists of a massif of hard old rocks ranging in age from pre-Cambrian to Jurassic. The whole area, with the exception of several old lake basins, has probably been land since the latter part of the Mesozoic. The massif forms a plateau with an average elevation of 3,000 feet. The western edge is clearly defined, being marked by the conspicuous line of hills familiar to every traveler by train from Rangoon to Mandalay. Along this line the Tertiary rocks dip sharply away from the old massif, but the junction is rarely visible.

2. *The Western Fold Ranges.*—In the west of Burma the dominating feature is a great range of fold mountains. The range is complex and broad in the north, where it comprises the Naga, Chin, and other groups of hills; but southward it narrows to form the Arakan Yoma. The actual physical structure terminates in Cape Negrais, but structurally the same fold continues through the Andaman and Nicobar Islands into Sumatra. In Burma several peaks reach 10,000 feet. Very little is yet known of the geology of the range. The structure appears to be anticlinorial, with a central core of crystalline rocks. Triassic, Jurassic, and Cretaceous rocks are involved in the folding, as well as the Tertiary sediments. There is good reason to believe that the fold originated in Cretaceous or earlier times and grew gradually during the Alpine movements of the Tertiary period. The fold gave rise to a narrow land barrier from Eocene times onward.

3. *The Central Tertiary Basin.*—Between the Arakan Yoma on the west and the Shan Plateau on the east lies the great region of Tertiary rocks in Burma. It

[1] Oil-field statistics are published annually, about ten months after the close of the year, in the "Review of the Mineral Production of India," *Records Ecological Survey of India.* Every five years a special volume of the *Records* is devoted to a "Quinquennial Review of the Mineral Production of India." The last published embraced the period 1919–23.

corresponds roughly with the basins of the Chindwin-Irrawaddy and the Sittang rivers, and it is with this region that the present paper is primarily concerned.



FIGS. 2. AND 3.—From *Geol. Mag.* (London, 1922), p. 483. Figure 2, the physiographic regions of Burma; Figure 3, the early Tertiary geography of Burma.

4. *The Arakan Tertiary region.*—Between the Arakan Yoma and the Bay of Bengal lies another area of Tertiary rocks, forming part of the Assam area of deposition.

THE TERTIARY GEOLOGY OF BURMA

In early Tertiary times Burma may be pictured as partly covered by a long narrow gulf of the sea, with the Shan Plateau forming the land mass on the east and the central ridge of the Arakan Yoma forming a narrow strip of land on the

west. The gulf would be broader than appears at the present day, owing to the extensive lateral compression and folding which has since taken place. The gulf was open to the sea to the south, but into the northern end there probably poured several great rivers. Possibly the Tibetan course of the Brahmaputra is a remnant of this river system; at a later stage, rivers of which the Chindwin and the Irrawaddy are the modern representatives took its place. *The whole history of the Tertiary period in Burma may be summed up as the story of the infilling of this gulf by river-borne sediments from the north and by marine sediments in the south.* On the whole, therefore, there has been a spread of continental deposits from the north, pushing the marine waters farther and farther south. This process is still going on, for year by year the delta of the Irrawaddy encroaches on the shallow Gulf of Martaban.

The conception of this great fundamental idea underlying the Tertiary geology of Burma is due to G. de P. Cotter.[1]

The gradual infilling of the trough has, however, been interrupted at intervals by lateral folding movements. These movements resulted in the gradual uplift of the Arakan Yoma and, at a later stage, of the Pegu Yoma and other folds. Each movement of folding, however, caused a temporary increase of the depth of the center of the basin and a consequent return northward of marine conditions. *Thus it is found that the gradual southward retreat of the sea was interrupted by temporary northward movements which have left their mark as wedges of marine strata tailing out northward.* This development of Cotter's ideas was brought out by the writer's work in the Chindwin,[2] and was embodied by him in a generalization referring to the whole Tertiary region of Burma.[3]

Since then, it seems to have been generally acceptable to geologists,[4] and the writer has adduced further evidence.[5] Murray Stuart also concurs, except that he considers that the Burmese and Assamese gulfs were joined at their northern end and that the Arakan Yoma formed an island rather than a peninsula.[6]

The Tertiary rocks of central Burma fall into three main divisions:

Irrawaddian (Mio-Pliocene)
Peguan (Oligo-Miocene)
Eocene

All horizons from the middle of the Eocene to the top of the Peguan may be petroliferous, and the oil in existing fields is obtained from all horizons from the base to the

[1] Cotter, "The Geotectonics of the Tertiary Irrawaddy Basin," *Jour. Asiatic Soc. Bengal*, n.s., Vol. 14 (1918), pp. 409–20.

[2] Stamp, "Geology of Part of the Pondaung Range, Burma," *Trans. Min. Geol. Inst. India*, Vol. 17 (1922), pp. 163–80.

[3] Stamp, "An Outline of Tertiary Geology of Burma," *Geol. Mag.*, Vol. 59 (London, November, 1922), pp. 481–501.

[4] Cotter, *Proc. Pan-Pacific Congress*, Australia, 1924; Cotter, "The Mineral Deposits of Burma," *Supt. Govt. Printing*, Rangoon, 1924; Coggin Brown, *Rec. Geol. Survey India*, Vol. 56, pp. 65–108.

[5] Stamp, *Geol. Mag.*, Vol. 62 (London, November, 1925), pp. 515–23.

[6] Stuart, *Jour. Inst. Petrol. Tech.*, Vol. 11, No. 50, and *Rec. Geol. Survey India*, Vol. 54. Part 4, 1923.

top of the Peguan and probably from the higher Eocene. It is accordingly a matter of no little practical importance to attempt to trace the connection between the petroliferous and stratigraphical horizons.

The change in facies of the Eocene and Peguan from predominantly fresh water in the north to predominantly marine in the south has just been emphasized.

These changes have a very definite significance in the search for oil. It is found that the fresh-water sands (Irrawaddian) and fresh-water clays, with remains of crocodiles, turtles, and mammals, are entirely devoid of oil; the deeper marine water clays are equally devoid of oil. *All the petroliferous horizons are definitely associated with intermediate conditions.* In passing, it may be noted that the Tertiary coals of Burma are also associated with intermediate conditions, but occur in deposits indicating closer association with fresh water than does the oil.

The old idea that the oil-bearing beds of Burma occupied a definite stratigraphical horizon is wholly fallacious, and the long-standing controversy as to whether this petroliferous horizon was older or newer than the Kama clay is equally futile. Once it has been realized that the petroliferous deposits of Burma change their horizon in this way, it is surprising how remarkably well the lithological and paleontological evidence fit together.

It is useless to pretend that geologists in Burma have had, or even yet have, an easy task. It is always possible to "map" lithological horizons; but what actually happens to the petroliferous horizons has been learned in most cases by the very expensive method of unsuccessful drilling. *Burma abounds with examples of promising structures which have yielded nothing.* There can be little doubt that the failures have been due to the oncoming of more marine conditions experienced in any one horizon as one proceeds southward. Beds on the same horizon as the best sands of Yenangyaung are barren marine clays of Minbu and, judged by the present succession of failures, at Ondwe. Yet these localities are only some 20 miles farther south.

EOCENE

The Eocene beds are exposed mainly down the western margin of the old gulf. They are as yet imperfectly described, but reach an enormous thickness—not less than 12,000 feet in measured sections. The sequence about Lat. 22° N. is:

Yaw shales (marine)
Pondaung sandstones (fresh-water in upper part, marine below)
Tabyin clays (marine)
Tilin sandstones (partly fresh-water?)
Laungshe shales
Paunggyi conglomerate

In places the Paunggyi conglomerates rest unconformably on older rocks, but at other places there is an extensive series of lowest Eocene shales underlying them.

The sandy beds, like the Tilin sandstones and the Pondaung sandstones, become attenuated and disappear southward; marine clays like the Yaw shales become attenuated and disappear northward. All sediments may be replaced by fresh-water clays—generally gray and red mottled—in the north. The Yaw shales,

for example, are typically marine as far north as the Lower Chindwin District,[1] but in the Upper Chindwin pass into a series of coal measures with the well-known coals of Kalewa.

PEGUAN-IRRAWADDIAN

Roughly speaking, the Peguan corresponds to the post-Eocene marine beds of Burma. Over most of the country it is overlain by a great fresh-water group, the Irrawaddian. In the extreme north, however, the whole succession is fresh-water and the lower part has there often been called "Fresh-water Pegu."

It is with the Peguan that the oil geologist is especially concerned. As the group reaches a measured thickness of more than 14,000 feet in places, subdivision is essential. For the purposes of detailed geological mapping local lithological horizons can usually be distinguished, but it must be remembered that the several beds are not constant in their horizon. About the middle of the Peguan period there was a marked marine invasion northward, and for this reason the Peguan rocks fall into three broad groups:

3. Upper sandy or mixed group
2. Middle clay group
1. Lower sandy or mixed group

For the purpose of comparison with previous papers it may be noted that the lower group includes the Shwezetaw sandstones; the middle group is the Sitsayan shales (south) or Padaung clays (north); while the upper group includes the exposed Peguan of most of the oil fields, together with the Prome sandstones of Lower Burma. A thin band of clay intercalated in the Prome sandstones is the Kama clay, which, partly owing to confusion with the Sitsayan shales, has assumed an altogether unwarranted importance in the literature of Burmese geology.[2]

The remarkable way in which the lithological beds change their horizon has been demonstrated not only by field mapping but by the separation of a number of "stages" on a paleontological basis. The stages are as follows:[3]

5. Kama stage
4. Migyaungye stage
3. Singu stage
2. Padaung stage
1. Shwezetaw stage with Kyet-u-bok bed at the base

[1] Stamp, "Geology of Part of the Pondaung Range," *Trans. Min. Geol. Inst. India*, Vol. 17, pp. 161–80.

[2] The Kama clay is virtually a myth. It is a clayey band—one among hundreds—in the predominantly sandy part of the Upper Peguan. It attracted the attention of Theobald (1870–74) by its well-preserved fossils, afterward described by Noetling. The band was wrongly located, as now entirely hidden by alluvium, by Murray Stuart (1910), but correctly relocated by Vredenburg (1921). The writer located it, after considerable search, in 1922. The sooner the Kama clay is forgotten by oil geologists, the better.

[3] With the exception of the insertion of 4 and the elimination of the Pyalo stage, the stages are the same as adopted by Vredenburg. Vredenburg established his horizons by detailed paleontological studies; the writer, by careful mapping and collecting in the field. It is unfortunate that most of Vredenburg's material came from the Peguan members of the oil fields, and not from the main Peguan outcrops of the west; but this need not invalidate his studies.

The exact status of the "Akauktaung stage," said to exist above the Kama stage in Lower Burma, is at present uncertain.

It may be noted in passing that the Peguan rocks range in age from the base of the Oligocene to about the middle of the Miocene; the Irrawaddian, probably from the mid-Miocene onward. The Irrawaddian consists for the most part of coarse, false-bedded sands.

The diagrammatic section (Fig. 4) illustrates the relationship between the paleontological stages and the lithological stages far more clearly than pages of description would do. The interesting point to notice is the way in which the upper petroliferous horizons pass into newer and newer beds as one moves from north to south. It is obvious that only a careful consideration of both the lithological and paleontological evidence will give a clue to the position of the petroliferous horizons in any given locality. In drawing such a diagram as Figure 4, it is necessary to choose some series of lines as datum lines. Accordingly, the time planes, that is, the dividing lines between the paleontological stages, have been drawn horizontal, and the lithological horizons fitted into them. *Thus the thicknesses of the beds are not shown drawn to true scale.* Actually about 100 feet of Sitsayan shales probably took as long to form as 1,000 feet of sandy beds. Figure 4 has been somewhat simplified. There are subsidiary wedges of sandstone in parts of the Sitsayan shales which have not been indicated.

It must be remembered that Figure 4 is a diagrammatic section from south to north, that is, longitudinally, through the Tertiary trough.

When any group of beds is studied in detail over a limited area, and lithological horizons and paleontological stages both mapped, a section drawn to scale appears as in Figure 5.

But from what has been said of the conditions of deposition, there must obviously be considerable variation from west to east, from the sides to the center of the trough of deposition.

Actually, the position was complicated by the existence, down the center of the gulf, of a ridge (probably a submerged ridge) which divided the gulf into halves. The sediments deposited in the eastern and western halves of the gulf were somewhat different. *All the oil-bearing beds were laid down in the western half of the gulf.* Along the dividing ridge volcanic activity broke out, and a group of volcanoes marks its approximate position around Monywa on Chindwin River. The largest volcano of all is Mount Popa, nearly 5,000 feet high. The present fold range, the Pegu Yoma, marks the southern continuation of the ridge.

Lateral compression of the gulf and consequent formation of folds running roughly north-south went on until the end of the Pliocene and probably into Pleistocene times. The oil fields lie on the folds so formed. The following sections (Fig. 6) illustrate the present structure of the central basin of Burma. The volcanic

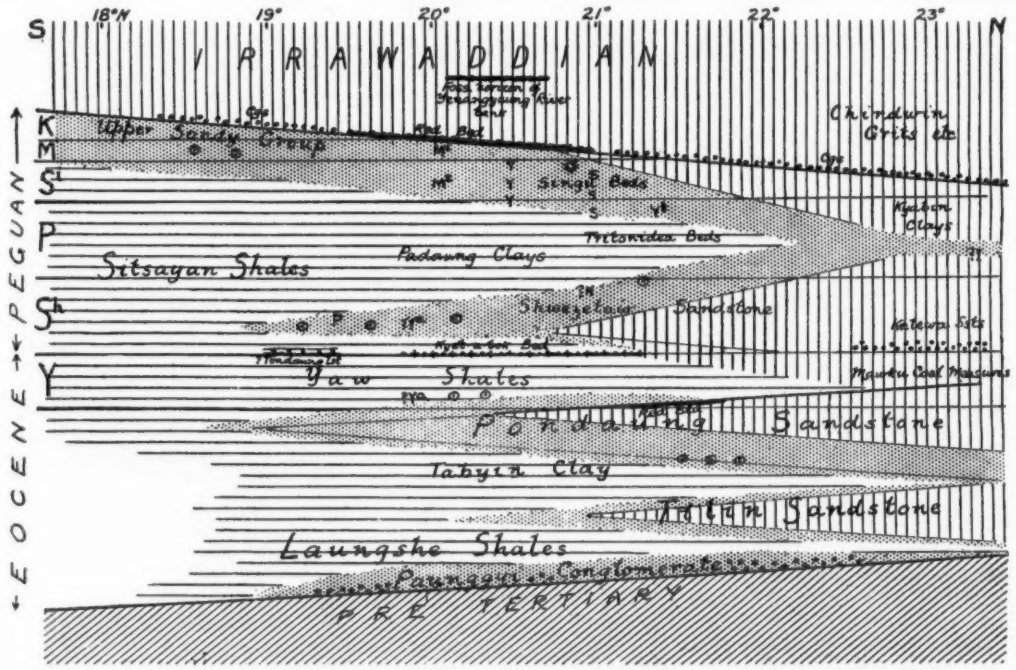


FIG. 4.—(From *Jour. Inst. Petrol. Tech.*, 1927). Diagrammatic section from south to north through the Tertiary trough of Burma.

LITHOLOGY

Vertical lines = freshwater beds; nearly all with silicified fossil wood and some remains of mammals, crocodiles and turtles. Mainly coarse sands.
Dotted = marine and estuarine beds, mainly sandy.
Horizontal lines = marine and brackish-water beds, predominantly clayey.

PALEONTOLOGY

Y = Yaw stage; Sh = Shwezetaw stage;
P = Padaung stage; Si = Singu stage;
M = Migyaungye stage; K = Kama stage.

OIL GEOLOGY

?I = Probable oil horizon of Indaw.
Yt = Oil horizon Yenangyat.
S = Oil horizons of Singu.
Y = Oil horizons of Yenangyaung.
M¹ = Oil horizon of Minbu (N).
M² = Oil horizons of Minbu (Yethaya and Tagaing).
P = Oil horizon of Padaukpin.
?Ya = Oil horizon of Yenanma (alternative).
?N = Probable oil horizon of Ngahlaingdwin.
⊙ = Oil horizons not commercially exploited.

rocks shown may be taken as indicating the dividing line between the western and eastern halves of the old gulf, and all the oil fields lie to the west of that line.

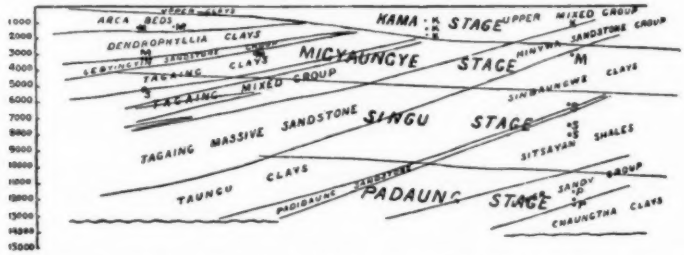


FIG. 5.—From *Geological Magazine*, London. Diagrammatic section, drawn approximately to scale, showing the variation in lithology in the upper Peguan of central Burma from northwest to southeast. The length of the section is about 30 miles and stretches from above the town of Minhla to below the town of Sinbaungwe, both on the Irrawaddy. Important fossiliferous localities are shown by dots and the diachronous behavior of the lithological groups is well shown.

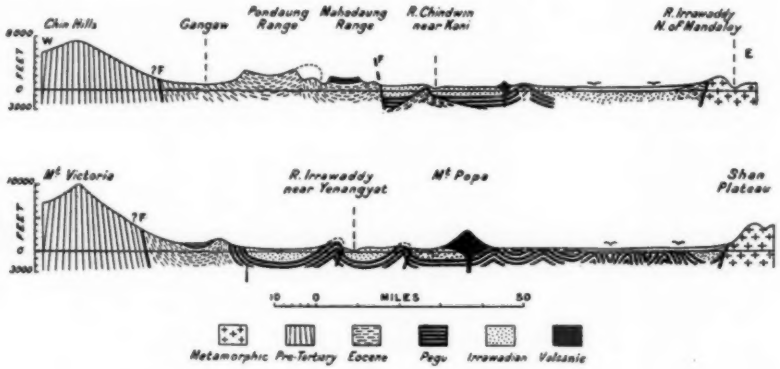


FIG. 6.—Sections (from *Jour Inst. Petrol. Tech.*, 1927)

A BRIEF DESCRIPTION OF THE EXISTING OIL FIELDS

The oil fields of Burma are found as a long line running from north to south near the center of the synclinal trough which forms the center of Burma. It may be said at once that the important fields (*a*) lie near the center of the trough, (*b*) are on gently folded anticlines—puckers in the synclinal trough.

There are half a dozen quite minor fields, and it is found that these either (*a*) are slightly away from the center of the trough, or (*b*) are highly folded, or irregular, structures.

1. *Indaw.*—The Indaw field was unknown when Pascoe wrote his memoir. It was discovered rather more than a dozen years ago by the geologists of the Indo-Burma Petroleum Co. Ltd., and production is first recorded officially for 1918. Structurally it is a fine, gently folded open dome, and the field has great possibilities, since production up to the present has been from shallow sands. Deep testing is being carried out, but so far has been unsuccessful, due to drilling difficulties and heavy gas. Indaw is situated in the wet zone of Upper Burma, north of the Dry Belt, and health conditions have caused much trouble, but active measures have been taken to combat fever.

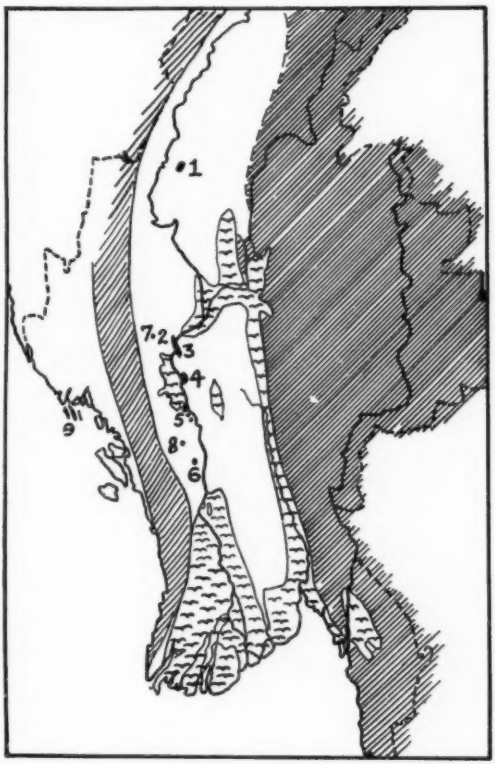


FIG. 7.—Map showing position of oil fields: 1, Indaw; 2–3, Yenangyat-Singu; 4, Yenangyaung; 5, Minbu; 6, Padaukpin; 7, Ngahlaingdwin; 8, Yenanma; 9, Arakan coast.

The company has followed the policy of steady development; the oil is sent by pipe line and refined at Pantha (22 miles distant) on the River Chindwin, whence it is sent down the river and supplies the local markets of Upper Burma. The oil field is about 50 miles due south of Homalin (Fig. 1). As will be explained in a later section, the petroliferous rocks of the great oil fields of Yenangyat-Singu and Yenangyaung pass northward into barren, fresh-water strata, and the oil-bearing rocks of Indaw are probably much older than in other parts of Burma. The production at Indaw is shown in the following figures:

PRODUCTION AT INDAW

	Gallons		Gallons
1918	473,800	1922	1,210,914
1919	1,085,030	1923	1,311,664
1920	1,022,766	1924	1,474,898
1921	1,182,782	1925	1,385,977

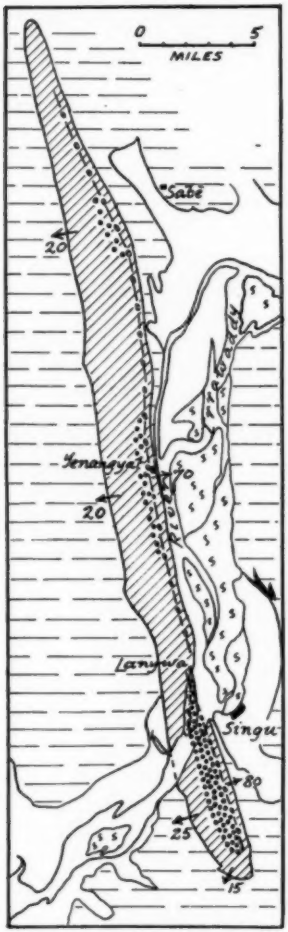


FIG. 8.—Sketch map of the Yenangyat-Singu oil fields, showing the long narrow fold of Peguan rocks (diagonal lines) surrounded by Irrawaddian (horizontal lines). The coarse dots show the approximate limits of the oil fields. The Sabè field is not mentioned in the text, as its production is included with Yenangyat. The way in which the river Irrawaddy cuts off the northern end of the Singu field is to be noticed; *ss* are sandbanks. The dips shown are generalized and apply to the highest Peguan.

2–3. *Yenangyat-Singu.*—Yenangyat and Singu should, geologically speaking, be described together, since they form part of one long anticline about 30 miles from north to south and striking a few degrees west of north. The fold is, however, breached by the River Irrawaddy; Yenangyat field lies to the north; Singu field, to the south. Like many of the folds of central Burma, the Yenangyat-Singu structure has a gentle westerly limb and a steep, almost vertical, easterly limb. Indeed, in the case of Yenangyat the eastern limb is slightly overfolded. The position of the two main fields on the fold is determined by the presence of crest-maxima. The rocks brought up by the fold are Peguan (Oligocene-lower Miocene) in age, the surrounding rocks being the barren fresh-water Irrawaddian sands. The Peguan rocks themselves pass steadily northward into fresh-water deposits, and at the northern end of the Yenangyat fold this change may be seen taking place. This is one reason why the northern end of the fold is non-productive, and seems also to account for the rapid exhaustion of the northern of the two fields—Yenangyat.

The fold has been more extensively denuded at Yenangyat than at Singu, and many of the productive sands of Singu outcrop at Yenangyat. This is another reason for the poverty of Yenangyat when compared with Singu. The exhaustion is shown by the following figures:

PRODUCTION AT YENANGYAT

	Gallons
1893	163,794
1898	6,550,422
1903 (peak)	22,668,312
1908	6,578,850
1913	5,499,191
1917	6,700,000
1918	4,739,587
1919	4,123,387
1920	3,176,231
1921	2,510,533
1922	2,413,416
1923	1,700,035
1924	1,594,517
1925	1,562,444

Native hand-dug wells existed long before 1893, but that year is the first in which production is recorded from drilled wells. The Burmah Oil Company commenced operations at Yenangyat in 1891, and is the principal company still working the field.

Singu, in contrast to Yengyat, has still great reserves, and its production is likely to increase. A promising area lies in the bed of the Irrawaddy between the two existing fields, and steps are being taken to reclaim a portion of this area and develop it. A shallow part of the river is being shut off by a rubble wall, and drilling is to be carried out on the land so reclaimed. This scheme is known as the Lanywa scheme, since the wall starts near the village of Lanywa, across the river from the Singu field. The Singu field was discovered by G. E. Grimes, a geologist of the Geological Survey of India, only a few days before cholera claimed him as a victim. The greater part of the field is operated by the Burmah Oil Company, which first obtained oil in October, 1921. An important tract at the southern end of the field is operated by the British Burmah Petroleum Co. Ltd., and its associated company, the Rangoon Oil Co. Ltd. The rights over the tract of land to be reclaimed from the river bed belong to the Indo-Burma Petroleum Co. Ltd.

The production of Singu is shown in the following table. The decrease in 1923 and 1924 is to be attributed largely to labor troubles, particularly to the great

PRODUCTION AT SINGU

	Gallons
1902	245,390
1903	5,617,371
1904	23,549,759
1908	43,048,948
1913	63,538,710
1918	61,035,982
1919	93,626,506
1920	95,256,753
1921	104,167,749
1922	92,107,998
1923	87,476,474
1924	79,938,430
1925	95,262,519

strike in 1923. The figures are particularly interesting, as one would scarcely think them indicative of a field with good reserves; but they are consistent with the policy of the steady and truly scientific exploitation which is the strong feature of the operating oil companies.

4. *Yenangyaung*.—Yenangyaung has been so often described that it will be but briefly mentioned here. It is a gentle dome, elongated north-northwest and south-southeast. It is situated right in the middle of the Tertiary trough of Burma. One feature to be noticed is the favorable gathering ground for many miles around.

This is illustrated in Figure 9. The oil comes from Peguan rocks. Considering its size, Yenangyaung can lay claim to being one of the wonder fields of the world, the production of 3,000,000,000 gallons since 1900 having come from an area of slightly more than one square mile. Two portions of the field, named the Beme and

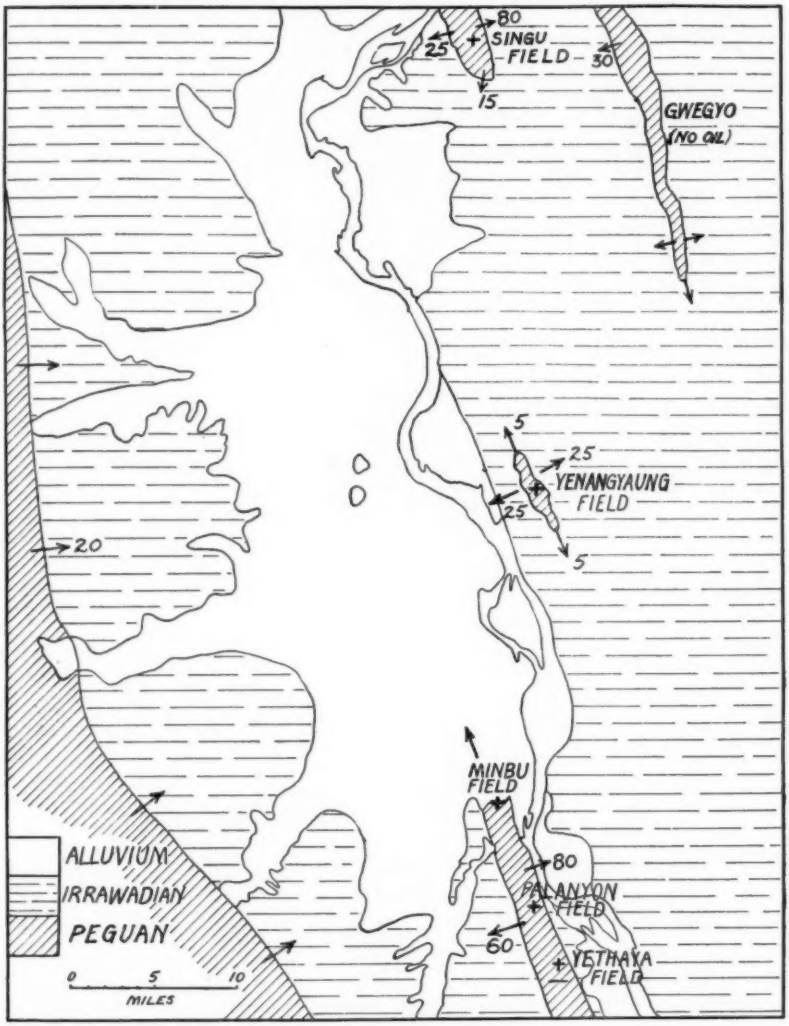


FIG. 9.—Sketch map showing wide gathering-ground, Yenangyaung, and relation of neighboring folds. Dips are generalized.

Twingon reserves, were set aside by the government for the use of the hereditary native owners (Twinzayos). Though some oil is still obtained by native hand-dug wells, the Twinzayos have sold nearly all their well sites to the big companies, and it is in these reserves that competition has been and still is so extraordinarily keen. The minimum distance between well sites is 60 feet; the price demanded by the Twinzayos for a site has risen steadily from less than 50 to 150,000 rupees; there are now scarcely any available sites of value remaining. A considerable quantity of oil is still obtained from native hand-dug wells, which some of the companies allow the natives to dig by the side of the drilled wells. Many companies operate in the reserves, the principal ones being the Burmah Oil Co., Indo-Burma Petroleum Co., British Burma Petroleum Co., and Rangoon Oil Co. Outside the

TABLE II

PRODUCTION OF YENANGYAUNG

	Native Wells (Gallons)	Drilled Wells (Gallons)
1888	2,548,171	17,468
1893	3,709,844	6,176,637
1898	5,550,119	8,238,708
1903	7,493,403	49,427,259
1908	7,950,376	115,687,120
1913	.....	200,555,668*
1918	.....	203,638,043
1919	.....	190,322,077
1920	.....	176,285,048
1921	.....	184,420,141
1922	.....	179,741,493
1923	.....	175,158,721
1924	.....	181,636,739
1925	.....	160,027,885

* This figure represents the combined production of hand-dug and drilled wells in 1913.

reserves—in the preserves of the Burmah Oil Co.—development has been steadier, and increase in the number of wells in the area seems likely to maintain production for some years to come. More recently oil has been struck at a depth of more than 3,000 feet in the southern portion of the field, more than a mile from the main producing area.

Native hand-dug wells are known to have been in existence as early as the eighteenth century, and more than 2,500,000 gallons were obtained from them in 1888, the year when the first drilled well was brought in.

5. *Minbu.*—Minbu, like Yenangyat-Singu, is another long fold of Penguan rocks surrounded, or almost surrounded, by Irrawaddian. Again there is a comparatively gentle western limb and an almost vertical eastern limb. Minbu still figures in the textbooks as what it was hoped it might be. As an oil field it never has been, and never will be, really important. A large part of the Peguan rocks exposed consists of a comparatively deep-water shale, incapable of carrying oil.

The upper sandy group, which is petroliferous, has been removed by denudation over most of the area. The existing production comes from three areas: (1) from the upper beds in the northerly-pitching northern nose of the main fold, north of

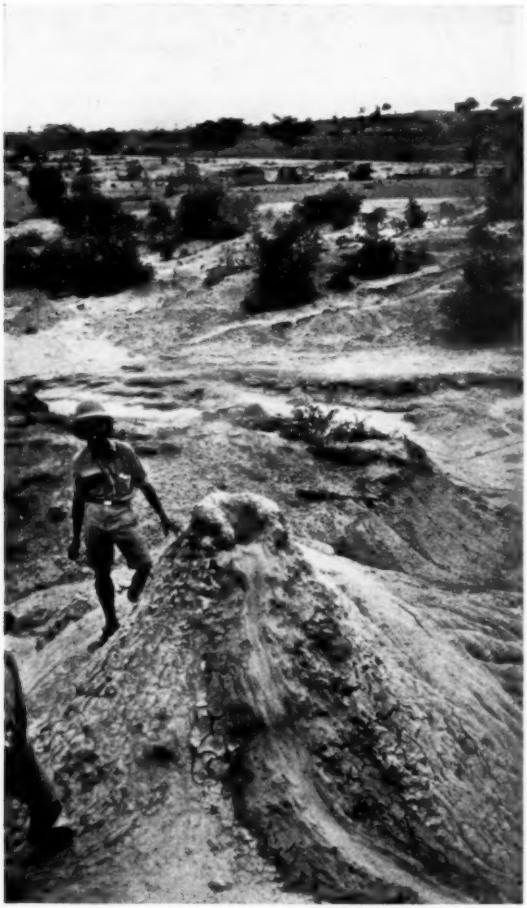


FIG. 10.—The crater of an active mud volcano, Minbu, 1925

Minbu town, and (2–3) from two subsidiary dome-structures developed in the midst of the main fold, where petroliferous sands at a much lower horizon are reached. These two structures are usually called the Palanyon and Yethaya fields.

In the first case the oil has accumulated on a sort of terrace resulting from a change in pitch. Many of the wells in this area (north of Minbu town) are still yielding a few gallons a day, although they reach only to a depth of two or three hundred feet and have been pumped continuously for as many as fourteen years. Yethaya and Palanyon are now the most steady producers.

Minbu has long been famous for its mud volcanoes, noticed as long ago as 1855 by T. Oldham. There are usually seven or eight vents; at the present day one has built up a mound of pale-gray mud nearly 100 feet high; others are simply broad pools of liquid mud through which huge bubbles of gas rise and burst every two or three seconds. The mud volcanoes lie along an important fault, and about two miles south of the producing wells at the north end of the field.

When Dr. Pascoe wrote his memoir, only small quantities of oil had been obtained. Production is first officially recorded in government returns in 1910. The first area to be developed was the one north of Minbu town; Palanyon and Yethaya were developed by the Burmah Oil Company at a later date. The wells at Minbu town are worked by the Burmah, British Burma, and the Yomah companies.

Although Minbu town, Palanyon, and Yethaya are really entirely distinct fields, they all lie in the Minbu district, and the productions are not separately stated in government reports.

PRODUCTION AT MINBU, PALANYON, AND YETHAYA

	Gallons
1910	18,320
1911	632,458
1912	3,896,365
1913	3,198,311
1914	1,683,190
1915	2,316,207
1916	2,043,542
1917	3,468,382
1918	4,826,735
1919	4,423,361
1920	3,835,198
1921	3,706,831
1922	3,940,416
1923	3,915,140
1924	3,829,044
1925	3,248,566

5A. *Tagaing or Minhla.*—Immediately to the south of the Minbu fold of Peguan rocks is another fold of rocks of the same age which pitches sharply to the north. It was on this northward-pitching nose that the small field of Tagaing was developed, but it has never paid its way.

TAGAING (OR MINHLA FIELD) PRODUCTION

	Gallons
1914	22,836
1915	25,920
1916	35,000
1917	30,000
1918	63,000
1919	113,784
1920	91,329
1921	66,372

Later figures not available.

6. *Padaukpin.*—Southward, the Peguan rocks, as a whole, become more argillaceous and probably of deeper-water type. The highest beds are more mixed and capable of carrying oil, while much lower in the sequence are sandy groups, locally petroliferous. One of these lower sandy groups is exposed in the gentle, oval-shaped dome of Padaukpin. While the structure is good, it is doubtful whether the petroliferous strata attain any considerable thickness. Since 1920 the field has been developed by the Indo-Burma Oilfields (1920) Ltd. Pumping started March 7, 1922, and the production as recorded by the company has been as follows:

PRODUCTION AT PADAUKPIN

	Barrels*
1922	13,524
1923	16,079
1924	15,208
1925	14,000 (approximate)
1926	17,000 (estimated)

* This is well-head production, and hence greater than the production (on which royalty is paid) shown in government returns.

The accompanying sketch map (Fig. 11) shows the nature of the fold and demonstrates the fact that although the structure is excellent, the beds being mainly of deeper-water type, the number of oil sands has been reduced to two or three. The field has been surveyed in detail by T. R. H. Garrett for the Premier Oil Co. Ltd., and by the geologists of the Indo-Burma Oilfields (1920) Ltd.

7. *Ngahlaingdwin.*—This field, which is really still in the exploration stage, is situated at the southern end of a long narrow fold of Peguan rocks. Farther north is the Pauk field, which has yielded a small quantity of oil. Ngahlaingdwin is being exploited by the British Burma Petroleum and the Indo-Burma Petroleum companies. The oil appears to come from the lower beds of the Peguan, and the structure belongs to the class of narrow folds situated west of the central line of the Tertiary trough. The drilling has not, so far, been successful, and operations are suspended.

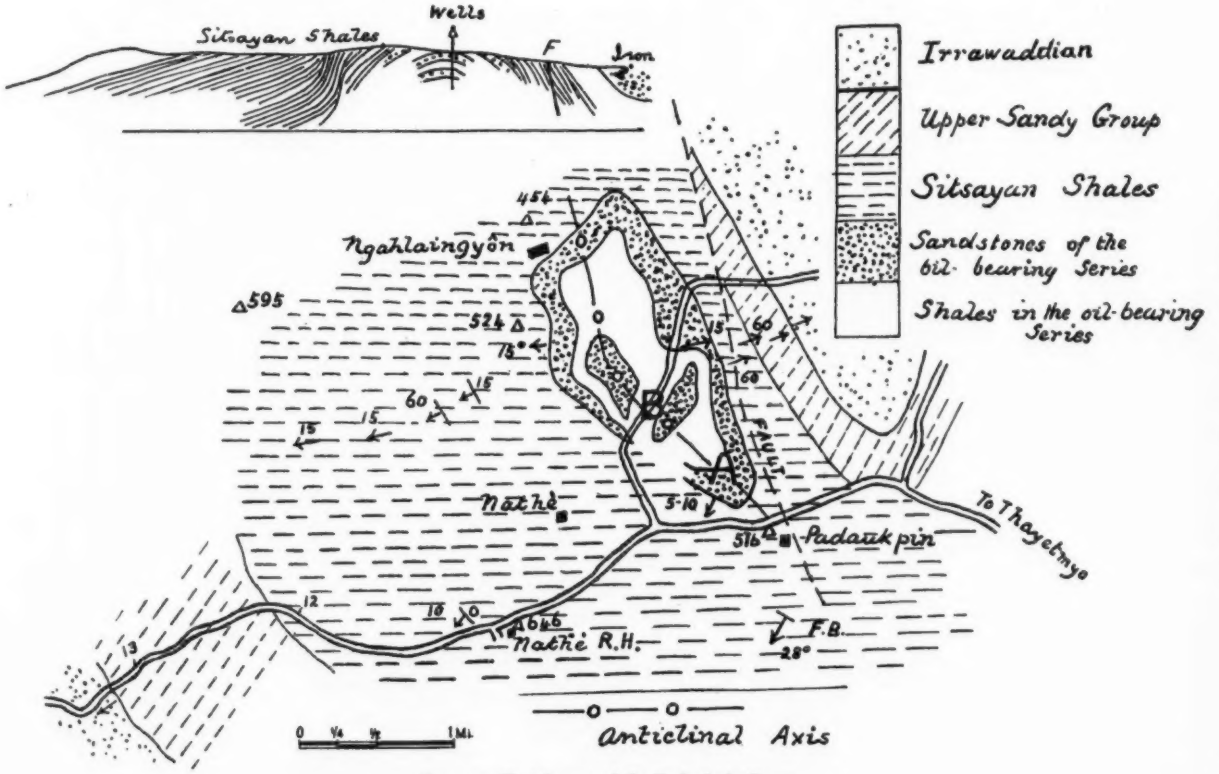


FIG. 11.—Sketch map of the Padaukpin Dome

8. *Yenanma.*—Yenanma is a remarkable little field which stands alone among the Burmese fields. It seems, on superficial examination, to consist of a pocket of oil-bearing sands situated in the midst of a group of laminated clays and sands forming a homocline (or monocline) with a steady easterly dip of 20° to 25°. However, as explained by Murray Stuart,[1] it is believed by some that these beds are thrust westward over folded rocks of similar or rather earlier age. Dr. Stuart considers that the oil pool lies actually in the fault plane, though the sections he has published show a hidden anticline lying below the fault plane. It should be mentioned, however, that this conception of the structure is not shared by many geologists who know Burma thoroughly well. Following along the outcrop, seepages may be traced for a distance of some 40 miles on two distinct horizons, one near the base of the Peguan and the other 2,000 or 3,000 feet lower, in the higher part of the Eocene. There may, therefore, be other oil pockets below the monocline, but there would seem to be no indication whereby they can be located. Yenanma is exploited by the Indo-Burma Oilfields (1920) Ltd., and the production, since pumping was commenced, January 12, 1922, has been as follows:

PRODUCTION AT YENANMA

	Barrels*
1922	54,295
1923	36,649
1924	33,854
1925	27,000 (approximate)
1926	17,000 (estimated)

* Well-head production as recorded by the company. The government returns for the Thayetmyo district, including both Padaukpin and Yenanma, as well as a few thousand gallons from Tagaing, are as follows:

	Gallons
1922	2,319,835
1923	1,818,584
1924	1,717,653
1925	1,320,009

9. *Arakan coast.*—Several of the closely folded anticlines of the Arakan coast are petroliferous, but the deposits appear to belong to a separate basin of sedimentation. As the writer has only casually examined this region, these occurrences will not be considered here. The oil is at present obtained mainly from two areas: Ramri Island in the Kyaukpyu district, and a small island south of Akyab in the Akyab district. The licensées at present are all natives and the oil is obtained by native methods; production is declining and does not now exceed 50,000 gallons annually. In 1924 it was 21,714 gallons; in 1925, 21,530 gallons, being 7,169 gallons from the Akyab district and 14,361 from the Kyaukpyu district.

THE CONDITIONS OF DEPOSITION OF THE OIL-BEARING BEDS

The rapid alternation of beds of impervious clay and porous sands almost precludes the possibility of extensive vertical migration of oil. Indeed, all the evidence which the writer has seen tends to support the view that the oil of Burma originated

[1] *Jour. Inst. Petrol. Tech.*, Vol. 11, No. 52 (October, 1925), pp. 481-85.

in the beds in which it is now found, and that only lateral migration has been important. All along the outcrop of the Yenanma and upper Eocene petroliferous horizons, little lens-shaped streaks—from $\frac{1}{8}$ inch to several feet in thickness—of sand saturated with oil may be found entirely surrounded by clay. It seems impossible that the oil could have got into such a position from outside. Similarly, in the great fields conditions are against vertical migration.

Presuming, then, that the oil originated where it is now found, certain definite conclusions may be formed:

1. Oil is never found in beds of definitely fresh-water or aeolian origin, such as the Irrawaddian.

2. Oil is never found in beds originating in deeper marine waters—"deeper" being here used in a strictly comparative sense. The Sitsayan shales—rubby, or concretionary shales—are a typical example, but there are beds which, from their laminated nature, might be thought capable of bearing oil, but which do not. It has been found that these beds are characterized by what is sometimes called a "*Pleurotoma* fauna," which is generally acknowledged to indicate deeper water than certain other mixed lamellibranch-gastropod faunas. The petroleum geologist is often apt to scoff at the use of fossils. The paleontologists are to blame to some extent for overemphasizing details of nomenclature. The oil geologist in Burma can learn a great deal of importance from the facies of an assemblage of fossils without knowing the name of a single one.

Oil is always found in strata in which the majority of the fossils are marine, but of shallow-water type. Traced along the strike into areas where the conditions more approached the fluvio-marine or fresh-water, the same beds in many places carry seams of coal. In all such cases oil is always found under more marine conditions than coal.

While, then, there is a very definite connection between the occurrence of oil and the conditions as indicated by fossils, the lithology and tectonics, as in other parts of the world, have controlled the accumulation of large quantities. Lithologically, oil in Burma is found in beds characterized by a rapid alternation of sands and shales, whether on a very small scale (say in layers of $\frac{1}{8}$ in.) or on a large scale. Crystals of gypsum are common, but are more characteristic of beds above the oil horizons, and many of the localities where gypsum is most plentiful are non-petroliferous.

It has already been pointed out that during the deposition of the oil-bearing beds, central Burma was occupied by a gulf into which fresh waters poured from the north. It is now possible to say that the oil-bearing rocks of Burma were deposited on the seaward side of a delta, and that the oil originated under such conditions of admixture of fresh and salt water as permitted the existence of a definitely marine though shallow-water fauna. Seaward (*Pleurotoma* shale facies), oil is not found; landward or riverward, its place seems to be taken by coal; under definitely fluviatile conditions the vegetable remains have been silicified, and fossil wood is very common.

Elsewhere the writer has made a detailed study of the banded sediments in which the oil sands occur. It is considered that the banding is due to the annual flooding of the old Tertiary rivers which embouched into the Burmese Gulf, and

FIG. 12.—Typical banded rocks of the type carrying oil sands

that each double lamina of coarse and fine sediment represents the deposits of a single year. On this assumption the writer has calculated that the Peguan period (Oligocene–lower Miocene) lasted about 2,250,000 years. The laminae of these "varved" sediments extend from $\frac{1}{2}\frac{1}{6}$ inch upward. Figure 12 shows a photograph of some of the coarser varved deposits. For further details, reference should be made to an earlier paper[1] by the writer.

[1] Stamp, "Seasonal Rhythm in the Tertiary Sediments of Burma," *Geol. Mag.*, Vol. 62 (London, November, 1925), pp. 515–26. Abstract in *Report Brit. Assoc.*, 1925.

CONCLUSION

In preparing this paper the writer has availed himself of all published matter known to him, of which the bulk is the work of the Geological Survey of India. Pascoe's Memoir contains an exhaustive bibliography up to 1911; most of the important references up to 1922 are included in Stamp's "Outline of the Tertiary Geology of Burma" (*Geol. Mag.*, Vol. 59 [1922], pp. 481–501). There are some corrections and additions to that paper in Stamp's "Seasonal Rhythm in the Tertiary Sediments of Burma" (*Geol. Mag.*, Vol. 62 [1925], pp. 515–28). For further details on the geological, and especially the paleontological, aspect of work in Burma, reference should be made to the writer's paper, "Conditions Governing the Occurrence of Oil in Burma."[1]

Practically nothing has been published concerning oil reserves in Burma. Not unnaturally, the companies operating in the country do not wish to broadcast information gained at great expense to themselves. People who talk glibly of vast tracts in Burma being virtually unexplored from the point of view of oil resources are talking rubbish. But so careful and scientific has been the development of the known fields that their production is likely to continue with little if any diminution far into the future.

[1] *Jour. Inst. Petrol. Tech.*, 1927.

THE COPLEY OIL POOL OF WEST VIRGINIA[1]

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Morgantown, West Virginia

ABSTRACT

The Copley oil pool of Lewis and Gilmer counties, West Virginia, is an illustration of synclinal accumulation of oil in sands which carry no water. Oil occurs in the deepest part of the basin, at the foot of a descending axis, being almost surrounded by gas in the anticlines on either side and along the higher synclinal axis northeastward. Southwestward the pool is terminated by poor sand rather than by changed structural conditions.

Oil production began by the completion of the Copley gusher in 1900, and still continues with a prospect that the pool will have ten more years of life. Gas production on a large scale began about 1909 and still continues, although the rock pressure, which originally was 550 pounds, has declined to 65 pounds.

Production is mainly from the Gordon Stray, Gordon, and Fifth sands of the Catskill series of the Upper Devonian. There is little prospect of lateral extension of the pool, but there is hope of new gas production in deeper sands. Oil production is not probable in deeper sands unless it be found in the Lower Devonian and Silurian beds 7,000–10,000 feet deep.

INTRODUCTION

The Copley oil pool is one of the best illustrations of synclinal accumulation of oil in sands which carry no water. This type of occurrence, which is largely peculiar to the Appalachian fields of North America, is common in the Devonian sands of West Virginia, Pennsylvania, and southern New York, and not unusual in the Mississippian sands of the same states and of the adjacent parts of Ohio and Kentucky, the region named being all within the drainage of the Appalachian Geosyncline which passes from western New York southwestward to Alabama, with its deepest depression in Wetzel County, West Virginia (Fig. 1).

The Copley pool is located in Lewis and Gilmer counties, West Virginia, on Sand Fork of Little Kanawha River, near the village of Copley, which is approximately 13 miles southwest of Weston and about the same distance northeast of Glenville, and nearly on a straight line between these two county seats. It was briefly described in 1904 by Dr. White[3] in a general volume on oil and gas in West Virginia, but in 1914 it was visited by Reger,[4] who mapped the structure on the Pittsburgh Coal and described the pool in more detail, giving numerous well records. Among the operators who contributed logs and data are the following: South Penn Oil Company, Hope Natural Gas Company, Pittsburgh & West Virginia Gas Company, Guffey & Galey, and United States Oil Company.

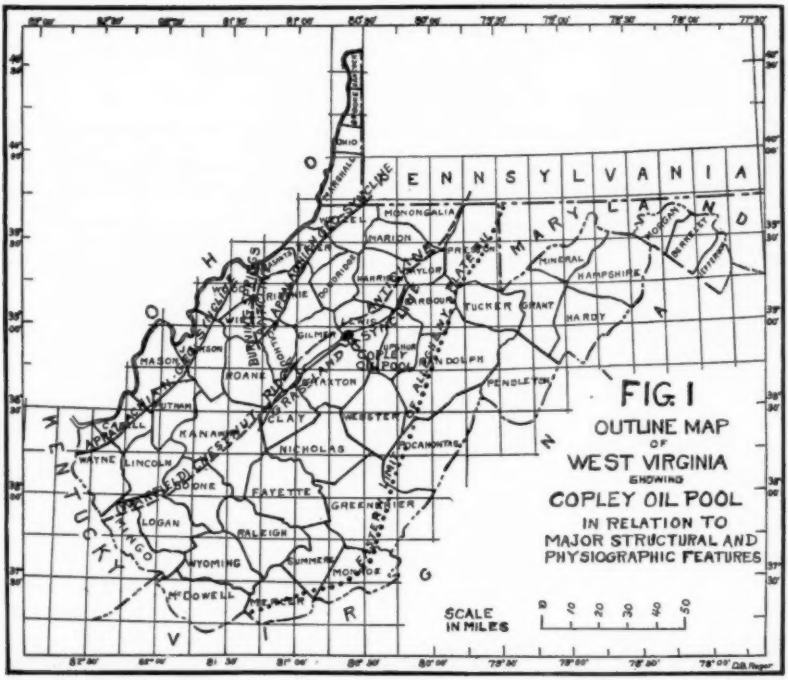
[1] Read before the Association by I. C. White at the Tulsa meeting, March 24, 1927.

[2] Assistant geologist, West Virginia Geological Survey.

[3] I. C. White, "Petroleum and Natural Gas," *W. Va. Geol. Survey*, Vol. 1*a* (1904), pp. 368–75.

[4] David B. Reger, "Lewis and Gilmer County Report," *W. Va. Geol. Survey* (1916), pp. 335–60.

The present study is largely founded on the data of 1914, with the addition of subsurface and regional maps and production records and with a discussion of the scientific aspects of the pool. The report last cited should be consulted for the detailed well records of the pool.



PHYSIOGRAPHY

Considered in its relation to the major topographic features of the Appalachian Province, the Copley oil pool lies within the area of the Allegheny Plateau as defined by Abbe,[1] or within the Cumberland Plateau as used by the United States Geological Survey. This plateau embraces the central and western part of West Virginia, as shown by Figure 1, and in fact its outliers extend farther east in West Virginia and western Maryland. For the present discussion, however, it may be most easily visualized as ending at the limits shown on Figure 1, since the land east of this boundary, having been crumpled into mountain folds, is of the Allegheny Ridge type, and the territory westward as far as the Ohio and Mississippi valleys, being gently folded, offers little or no topography as a guide to the struc-

[1] Cleveland Abbe, Jr., "General Report on the Physiography of Maryland," *Md. Weather Service* (1899), pp. 153 and 161–65.

LEWIS CO
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ture. This Allegheny Plateau, or sub-province, once a gently sloping plain, has been cut into innumerable ribbons by the drainage, which has left many sharp ridges. This plain is now somewhat raised along its eastern border where the elevation of the escarpment ranges from 2,500 to 4,000 feet above sea-level, but westward the plateau descends, steeply at first, and then more gently, until it is only about 1,400 feet at the Copley oil pool and 1,000 feet or less at the Ohio River. As shown by Figure 2, the topographic relief at Copley ranges from 500 to 600 feet, and the valley of Sand Fork is about 800 feet above sea-level. There are only narrow bottoms along the larger streams, and there is no flat land of consequence on the ridges.

HISTORY

The Copley pool was opened September 13, 1900, with the completion of the Michael Copley Heirs well No. 1 by the South Penn Oil Company. According to local report the well had been drilled to the top of the Gordon Stray sand, which appeared to be so soft that a shut-down was ordered for the night; but before morning the well drilled itself in and began flowing wildly. There being no pipe lines available, earthen dams were built across Sand Fork, which, fortunately, was almost empty of water on account of a protracted drought, and this expedient, in addition to a careful guard against fire, saved much of the oil until a line was laid.

The company record (Table II) indicates an initial production of 5,000 barrels a day, but this probably refers to flow that was gauged after the erection of tankage, since employees of the South Penn Oil Company and of the Eureka Pipe Line Company living at Copley, who laid the line to the well, estimate the first production as 10,000 to 12,000 barrels.

Following the discovery well the pool was rapidly developed, with an area of six or eight square miles of oil in which 150 wells or more were drilled, and with a large gas production in the adjacent higher structure, the main financial interests concerned being those previously mentioned.

STRATIGRAPHY

COLUMNAR SECTION

Disregarding the slight deposits of recent Pleistocene material along the valleys, Table I illustrates the general nature of the rocks to such depths as drilling has gone.

EXPOSED BEDS

Of the formations described, the Dunkard series of the Permo-Carboniferous and about one-half of the Monongahela series of the Pennsylvanian are exposed in the Grassland Syncline at Copley, but along the adjacent anticlines the full Monongahela and upper part of the Conemaugh are above drainage.

Dunkard series.—Of the Dunkard series, which has a maximum of about 1,200 feet along the Appalachian Geosyncline farther west, there remains at Copley a

TABLE I

GENERAL COLUMNAR SECTION

Age	Period	Series	Description	Feet
Paleozoic	Permo-Carboniferous	Dunkard	Gray or brown micaceous sandstones with red or sandy shales and thin coal seams; apparently non-marine	400+
		Unconformity?		
	Pennsylvanian	Monongahela	Gray or brown micaceous sandstones with red or sandy shales, coals, and impure limestones; apparently non-marine; only partly exposed above surface	350–400
		Conemaugh	Gray or brown micaceous sandstones with red or sandy shales, thin coals, and impure limestones; two or three marine horizons; below drainage	500–650
		Allegheny	Gray, coarse sandstones, with gray or brown sandy shales and fire clays; apparently non-marine	150–250
		Pottsville	Gray, coarse, and conglomeratic sandstones, with gray or brown sandy shales and fire clays; only one marine horizon known in Lewis County	300–600
		Unconformity		
	Mississippian	Mauch Chunk	Red and green shales with green, micaceous, flaggy and lenticular sandstones; lower part in these counties is probably marine	250–400
		Unconformity		
		Greenbrier	"Big Lime" of well drillers; gray crystalline limestone with sandy streaks; abundantly marine	50–150
		Unconformity		
		Pocono	Gray or brown, coarse, and conglomeratic sandstones and gray or brown sandy shales; middle part is probably marine	200–450
		Unconformity		
	Devonian	Catskill	Red or green shale with red or brown cross-bedded sandstones which are lenticular; apparently non-marine	400–450
		Chemung	Green flaggy and fine-grained sandstones with much green sandy shale; highly marine; not drilled through in this region	?

thickness of only about 400 feet, this being the lower third of the series. These rocks consist of rather heavy gray or brown sandstones, some of which carry quartz pebbles, and beds of red or sandy shale with some thin and impure coals. In this part no limestones occur, and so far as known there are no marine fossils, but throughout the state the calcareous members at higher horizons carry a non-marine fauna of ostracods and other small forms. A few vertebrate tracks and some other slight remnants of Permian quadrupeds have also been found at scattered localities in other counties. The series was first correlated as Permian by Fontaine and White,[1] from the abundant flora of northern West Virginia and southwestern Pennsylvania. No oil or gas production has been found in these rocks in West Virginia.

Monongahela series.—The Monongahela series lies just beneath the Dunkard and is the youngest formation of the Pennsylvanian. It consists of gray or brown micaceous sandstones, some of which are locally conglomeratic with quartz pebbles, red or sandy shales, coals, and impure limestones. Its base is formed by the great Pittsburgh Coal, which is an important key rock in the oil fields of the state. Its exposed thickness at Copley is only about 175 feet, but its character is visible along the Chestnut Ridge Anticline to the north and the Orlando Anticline farther south, where its full thickness is 350 to 400 feet. In this region several of its coals are almost absent, but enough of the Pittsburgh remains for use as a correlation bed. No marine fossils have been observed, but minute fresh-water ostracods and other types are frequently found, and there is a coal flora which is partly Permian and partly Pennsylvanian in character. Dr. White has frequently suggested that the Permo-Pennsylvanian boundary might be lowered into the Conemaugh series next below the Monongahela, because of the occurrence of Permian reptiles and other attendant phenomena in the Monongahela and Conemaugh rocks.

In the Monongahela series one oil sand, the Carroll (Uniontown sandstone), is known, being productive mainly in Ritchie County but being entirely above drainage in the Copley region.

SUBSURFACE BEDS

Conemaugh series.—The Conemaugh series, next beneath the Monongahela, is composed of gray or brown micaceous sandstones, some of which carry quartz pebbles, red or sandy shales, thin coals, and impure limestones. It has a thickness of 500–600 feet. The limestones and shales, as there are four horizons that are rather abundantly marine at exposures throughout the state, are good correlation zones at such localities; the coals also contain many plants of Pennsylvanian age. Although not exposed at Copley, the Conemaugh series is visible elsewhere in Lewis and Gilmer counties. As it exhibits little variation of character or thickness, its nature at Copley may be safely considered as much the same.

[1] William M. Fontaine and I. C. White, "The Permian or Upper Carboniferous Flora of West Virginia and Southwest Pennsylvania," *Penn. Geol. Survey*, Vol. PP (1880).

In descending order the Conemaugh contains five oil sands, as follows:

Minshall (Connellsville sandstone)
Murphy (Morgantown sandstone)
Moundsville (Saltsburg sandstone)
First Cow Run, or Little Dunkard (Buffalo sandstone)
Big Dunkard (Mahoning)

Of these five sands only the First Cow Run and Big Dunkard, so far as known, have made shows of oil or gas in Lewis and Gilmer counties, but these shows did not occur at Copley.

Allegheny series.—The Allegheny series, next beneath the Conemaugh, is distinguished by the absence of red shale, its principal beds being gray massive sandstones, many of which carry quartz pebbles, gray or brown sandy shales, and fire clays. Its thickness ranges from 150 to 250 feet. Coals occur plentifully farther south in Lewis County, but are seemingly absent at Copley. The series is not known to be definitely marine in West Virginia, but in parts of Pennsylvania and Ohio there is a fossiliferous limestone in the lower part. Pennsylvanian plants are plentiful in regions where coals occur.

In descending order the Allegheny contains the following oil sands:

Burning Springs (Upper Freeport sandstone)
Gas sand (Lower Freeport sandstone)

No oil or gas, so far as known, has been found in these sands at Copley, but elsewhere in the two counties involved there have been shows of gas.

Pottsville series.—The Pottsville series is next below the Allegheny, and, being the oldest formation of the Pennsylvanian, may be studied in the Lewis County panhandle 15 or 20 miles southeast of Copley, where it is composed of gray, coarse, and conglomeratic sandstones with white quartz pebbles, gray or brown sandy shales, and fire clays and coals. It has a thickness of about 600 feet. At Copley it is 500 feet or less in thickness, and its coals have largely disappeared. The series in this general region is only a remnant of the immensely developed series in southern West Virginia, where it is nearly 4,000 feet thick. In the panhandle of Lewis County it has only one known marine horizon, but its plant life is plentiful.

In descending order the Pottsville of this part of West Virginia contains several oil sands which have been imperfectly correlated but are generally listed as follows:

Gas sand of Marion and Monongalia counties, or Second Cow Run of Ohio (Homewood sandstone)
Gas sand of Cairo
Salt sand of Cairo
Cairo sand
Gas sand of Rosedale
Salt sand of Rosedale

Owing to deficient criteria for the correlation of these sands in regions where they are below the surface, they are frequently called the *Salt sands* without further effort at distinction, and in this list there are probable duplications. Some

of these sands produce oil and gas at other neighboring regions, but are not known to have made shows at Copley. The term "salt sand" is applied to them because of their common content of salt water.

Mauch Chunk series.—Separated from the Pottsville by an unconformity of large proportions, the Mauch Chunk series of the Mississippian comes next in descending order. Locally this group consists of red and green shales and green, micaceous, flaggy, and lenticular sandstones, with a limestone near the base that is probably marine in character. Its thickness in the region ranges from 250 to 400 feet. This is but half the thickness exhibited at the nearest outcrop at Webster Springs, 35 miles southeastward, and as the series is known to vary widely in its physical and paleontological aspects from place to place, it may not be described with certainty at Copley. In southern West Virginia, as recently described by Reger,[1] the series is nearly 3,500 feet thick and contains many heavy quartzitic sandstones and marine limestones and shales, together with several coals. At Mauch Chunk and Pottsville, Pennsylvania, on the contrary, it appears to be strictly non-marine, although there are several species of vertebrate tracks, and it is almost wholly composed of red mudstones, with only a few quartzitic beds. In regions like Copley, where it is deeply buried and where it represents only a decadent phase, its members cannot be definitely correlated.

One oil sand, the Maxton (Droop sandstone?), is generally recognized in the Mauch Chunk by the drillers, but it remains to be established that the same horizon is so called in different localities. Another formation, the *Little Lime* (Reynolds limestone), near the base of the series, has in places produced a little oil. Neither of these beds has been found valuable at Copley.

Greenbrier series.—The Greenbrier series, next under the Mauch Chunk, from which it is separated by an unconformity of minor rank, is locally composed of 50 to 150 feet of gray and probably crystalline limestone that is most certainly of marine origin, since its character is such at nearly all outcrops except at some localities north of the West Virginia–Pennsylvania state line. There is ample reason for belief that this remnant of a series that is 1,800 feet thick in southern West Virginia and even thicker in southwestern Virginia is mainly, if not entirely, the Union limestone member, which in turn is a most probable equivalent of the Maxville of Ohio and of the combined Gasper and Fredonia of more western states. This formation is known as the *Big Lime* by the drillers, and is a correlation bed of great value. Although productive of much gas in southern counties, where it is more sandy, it has afforded no oil or gas at Copley.

Pocono series.—The Pocono series, just below the Greenbrier, from which it is separated by an unconformity due to the local absence of at least 2,500 feet of sediments, is a group of clastic rocks composed of gray or brown, coarse, and pebbly sandstones, and gray or brown sandy shales. It has a thickness of 200–450 feet. For many years this series has been considered as essentially non-marine, with only rare occurrences of fossils. In recent years, however, a more intensive

[1] David B. Reger, "Mercer, Monroe, and Summers Counties," *W. Va. Geol. Survey* (1926), pp. 291–444.

study has revealed the presence of many marine fossils in the upper part of the lower half of the series, as recently stated by Reger,[1] and as also noted by Charles Butts,[2] of the U. S. Geological Survey. Probably the best correlation plane for subsurface identification in this series is the Sunbury shale, known to the drillers as the Coffee shale on account of its brown or black color. It is located just above the Berea sand. At its type locality in Ohio, as well as at outcrops in southern West Virginia, this shale contains *Lingula melie* and *Orbiculoidea* (*Linguladiscina*) *herzeri;* and these should presumably occur in deep wells across the Appalachian Geosyncline. In surface outcrops, however, the more plentiful and larger fossils of the Broad Ford sandstone, just above the Sunbury shale, are more easily recognized, a species of *Syringothyris* being common.

In descending order the oil sands of the Pocono are as follows:

Keener sand and Beckett sand of Milton
Big Injun sand (Logan sandstone)
Squaw sand
Weir sand (Broad Ford sandstone)
Berea sand

These Pocono sands have produced no oil and not much gas in valuable quantity in the Copley pool, although some of them are richly productive under similar structural conditions elsewhere in the state.

Catskill series.—The Catskill series, next below the Pocono, is the youngest formation of the Devonian in the Appalachian region. It is composed of clastic beds, among which red and green shales form the larger part, with red or greenish-brown, cross-bedded, lenticular sandstones. Its local thickness ranges from 400 to 500 feet. Generally considered as lacking in both marine and plant remains and as otherwise lacking readily distinguishable material, its outcrops have never received deserved attention. Recent studies by Reger,[3] however, have shown a constant plant horizon (*Saxton shale*), which is a good correlation zone, near the top of the series and extending over a wide belt of Pennsylvania and West Virginia. This horizon also carries a pelecypod fauna in Randolph County.

In descending order the Catskill contains the following oil and gas sands:

Gantz sand
Fifty-foot sand
Thirty-foot sand
Gordon Stray sand
Gordon sand
Fourth sand
McDonald or Fifth sand
Bayard or Sixth sand
Elizabeth or Seventh sand

[1] *Op. cit.*, pp. 503–32.

[2] Personal conferences.

[3] David B. Reger, "Pocono Stratigraphy of the Broadtop Basin of Pennsylvania," *Geol. Soc. Amer.*, Madison Meeting, December, 1926.

These sands comprise the well-known Venango group of Pennsylvania. Their correlation southward into West Virginia has been attempted almost solely by interval from well to well with the help of the superjacent and subjacent formations which are fairly certain. Owing to the lenticular nature of these sands, their recognition at most localities is doubtful at best, especially when additional sands appear, as they do in many places.

In the Copley pool the so-called Gordon Stray, Gordon, and Fifth sands have been the oil-producing horizons, the Gordon being the most prolific. The same sands have generally produced gas in the rising structure away from the Grassland Syncline.

Chemung series.—The Chemung series, next below the Catskill, a highly marine group of thin flagstones and shales generally olive-green in color, has seldom been reached by the drill at Copley. Elsewhere in the state some of its beds produce gas, but its further discussion is not herein appropriate.

LOG OF TYPICAL WELL

Figure 3 is a detailed graph of the record of the J. W. Cox well No. 1 (W. Va. Geological Survey No. 397), drilled by Guffey and Galey and located on Rock Run 0.6 mile north of Bealls Mills in the Copley oil pool. The drilling of this well commenced on a hillside below the base of the Permian, but penetrated nearly to the base of the Catskill and showed both the Pittsburgh Coal and nearly all the oil sands, reaching production in the top of the Fifth sand.

CONDITIONS OF DEPOSITION

Disregarding the Permian and Pennsylvanian sediments, which were mainly formed in bogs subject to periodic depression, the Mississippian and Devonian rocks were mostly accumulated in the shallow Appalachian sea, the source of the clastic material being old ranges of granitic or quartzitic rock which once existed near the present Atlantic seaboard and east of the present Appalachian Mountains. In all of the major groups, with the possible exception of the Greenbrier, there were stages of emergence during which land plants could grow. In the Mauch Chunk and Catskill also there is evidence of extensive oxidation, but it is by no means certain that all this oxidation took place when sedimentation was in progress. Much of it may have occurred in previous loci of the material, the red color being retained through any successive migrations.

COMPETENCY OF BEDS

With the possible exception of the Mauch Chunk and Catskill, which are of weaker material, the sediments occurring at Copley contain many heavy sandstones capable of offering much resistance to the thrust forces from ancient Appalachia farther east, this being especially true of the vast mantle of Permian and Pennsylvanian, 2,000 feet or more in thickness, which generally covers the Appalachian Geosyncline. It is very well known that several thousand feet of

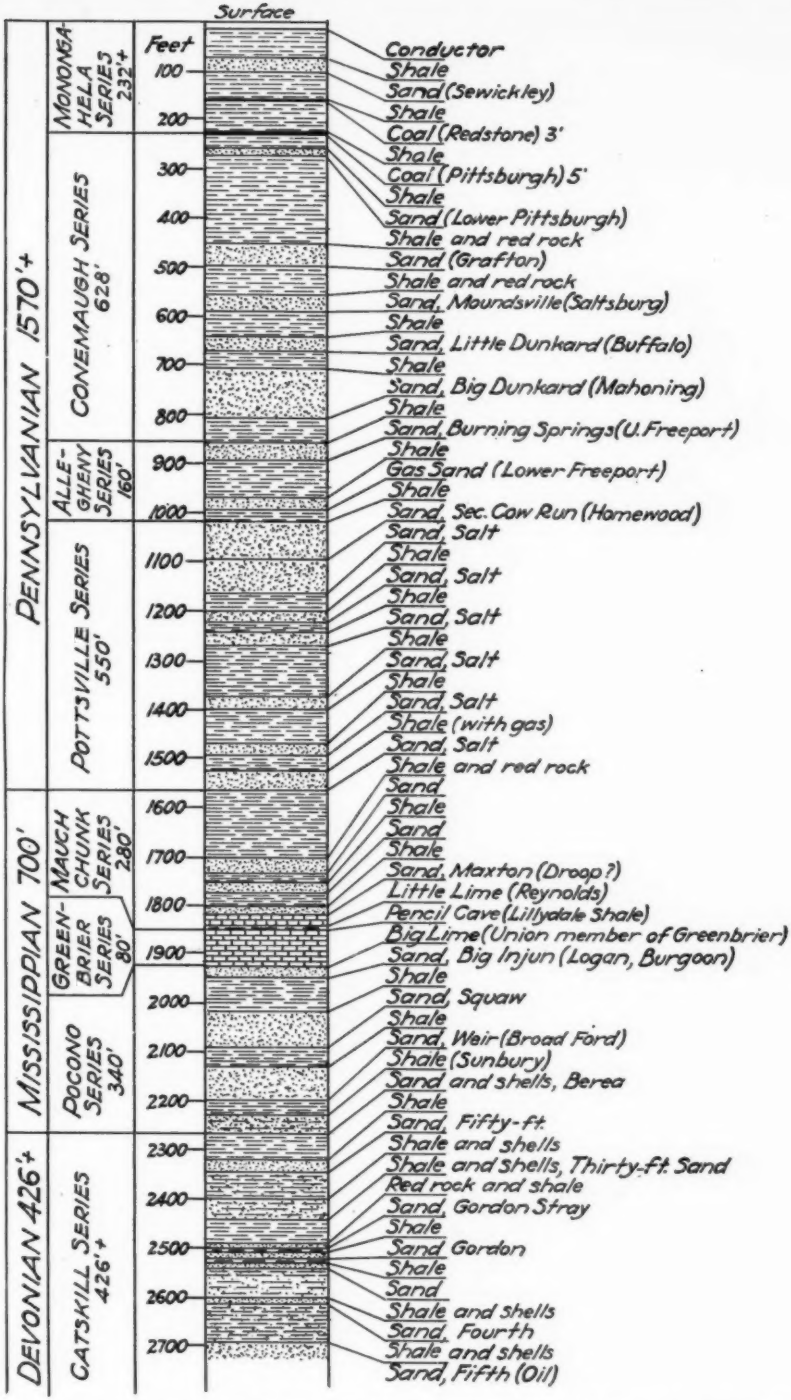

FIG. 3.—Log of typical well, J. W. Cox No. 1 (397), by Guffey & Galey, on Rock Run, 0.6 mile north of Bealls Mills, Copley oil pool, Lewis and Gilmer counties, West Virginia.

incompetent Devonian shales occur beneath the Catskill, but there is no evidence for belief that these have extensively buckled beneath the protective upper beds in regions so far removed from the mountains as Copley.

SURFACE STRUCTURE

REGIONAL FOLDS

Figure 1 indicates the position of the Appalachian Geosyncline which enters West Virginia at the southwestern corner of Pennsylvania and passes entirely across the state, entering Kentucky 10 miles or so south of its common corner with West Virginia and Ohio, but being interrupted, or staggered, by the Burning Springs Anticline, which crosses it obliquely in Wood and Wirt counties. Farther east the Chestnut Ridge (Warfield) Anticline makes a rather bold uplift across the state. Southeast of this anticline only a few major oil pools, of which Copley is one, have been found.

In the region between the Chestnut Ridge Anticline and the eastern limit of the Allegheny Plateau there are several small folds, of which the Grassland Syncline, holding the Copley pool, is an example. These minor folds are usually of comparatively short extent.

DETAILED STRUCTURE ON PITTSBURGH COAL

As shown by Figure 4, the surface structure drawn on the Pittsburgh Coal, which is beneath drainage at Copley but which outcrops in adjacent anticlines, is that of an almost symmetrical syncline rising toward the Chestnut Ridge Anticline, $3\frac{1}{2}$ miles farther northwestward, at the rate of 100 feet per mile, and toward the Orlando Anticline, 6 miles southeastward, at the rate of 75 feet per mile. The axis of this Grassland Syncline also rises northeastward at the rate of nearly 40 feet per mile in the first 6 miles from Copley, and this rise continues somewhat more gently for 13 miles, or 19 miles in all, from Copley, the average rate for the 19 miles being 30 feet per mile. Southwest of Copley the axis is nearly flat for 8 miles, after which an extensive rise begins. In the region of Copley the floor of the basin is nearly 1 mile wide, and this width increases southwestward until at some points it is nearly 2 miles wide.

SUBSURFACE STRUCTURE

CONTOURS ON GORDON OIL SAND

Figure 5 shows the subsurface structure on the top of the Gordon oil sand in terms of feet *below* sea-level.

COMPARISON WITH PITTSBURGH COAL CONTOURS

The Gordon contours show a less symmetrical relationship toward the adjacent anticlines, the axis of the basin being farther northwest and the rise toward the Chestnut Ridge Anticline being correspondingly steepened while the southeastward rise is perceptibly flattened. Also the floor of the basin is much narrower, and there are two depressions, one northeast and one southwest of Copley, which

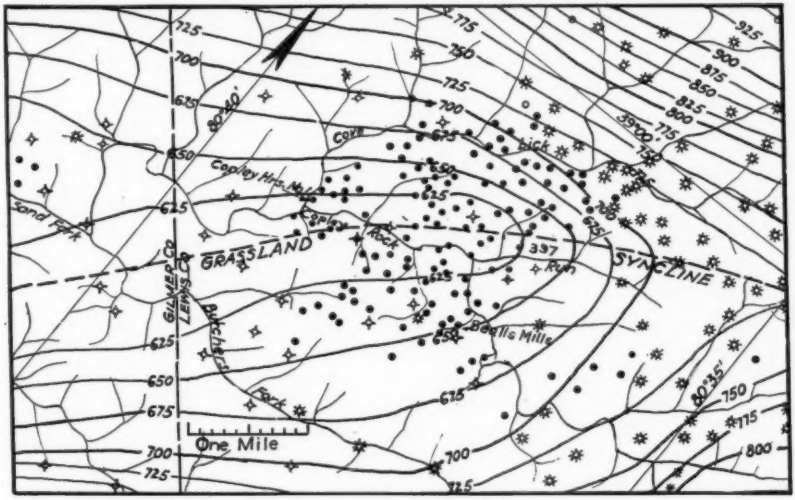

FIG. 4.—Surface structure, Copley oil pool, Lewis and Gilmer counties, West Virginia. Contours show elevations of Pittsburgh Coal *above* sea level, in feet.

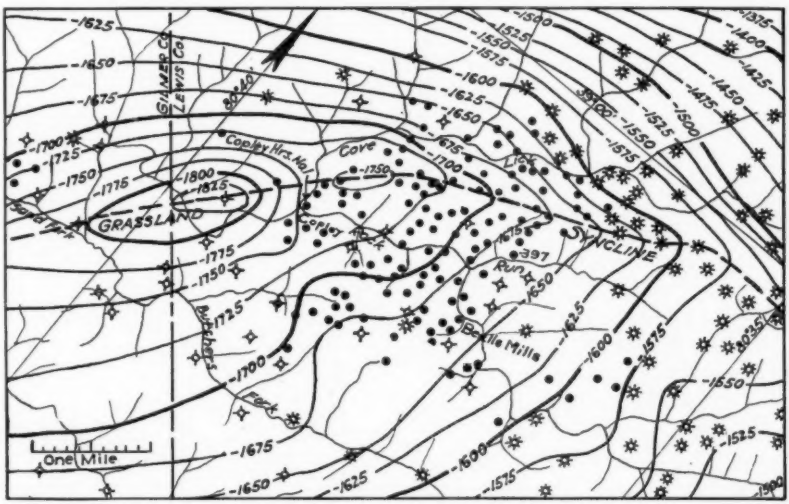

FIG. 5.—Subsurface structure, Copley oil pool, Lewis and Gilmer counties, West Virginia. Contours show elevations of top of Gordon oil sand *below* sea level, in feet.

do not show in the Pittsburgh Coal. These features indicate a slightly greater tendency toward buckling than occurs in the surface beds.

ABSENCE OF FAULTS

Like nearly all other West Virginia oil fields, the Copley pool structure is complicated by no faults of any kind. In the developed oil and gas pools of the state the only known fault is one which crosses Mingo County immediately southeast of the Chestnut Ridge (Warfield) Anticline.

RESERVOIR ROCKS

LITHOLOGY

Following a careless custom established by 40 years of drilling prior to the year 1900, the records of the Copley pool furnish regrettably few descriptive adjectives regarding the sands and other formations, and there are no petrographic studies of these sands in this or any neighboring region known to the writer. The nearest outcrop of the Catskill series is in Rich Mountain, 35 miles eastward, where, along the Staunton and Parkersburg pike, as measured by Reger, it has a thickness of 470 feet, or much the same as at Copley, but where there is probably a greater proportion of sandstone, since the locality borders on a region where rapid thickening occurs. As noticed at this exposure, the sandstones of the lower half, in which the Copley production appears to belong, are generally green or greenish-brown, medium-coarse, cross-bedded, and only moderately hard, there being many streaks of shale, some of which are oblique to the general bedding planes. Quartz pebbles are almost, if not totally, absent. This is the common nature of the Catskill sands that outcrop along the westernmost Allegheny ridges, except that in some regions they are reddish-brown instead of green.

CONTINUITY AND POROSITY

Thicknesses of the Gordon Stray, Gordon, and Fifth sands in the Copley region range from 5 to 25 feet, as a rule, and since they are of a lenticular nature, the absence of one or more of the three in any given well is not uncommon. Along the Grassland Syncline, southwest of Copley for 2 or 3 miles, most of the drilling resulted in failure, evidently due to the absence of sands or to a shaly or nonporous character. Farther on, in Gilmer County, 3 or 4 miles beyond Copley, a belt of productive Fifth sand was found at the mouth of Indian Fork, but apparently the Gordon was worthless.

No tests on porosity of the productive sands of the Copley pool are available, so far as known, either at this or any other locality in West Virginia.

ORIGIN

The Catskill sediments, in which the productive sands at Copley belong, are generally considered as highly oxidized, indicating long exposure to the air. It is not evident, however, that all this exposure took place during the present cycle of deposition. It is possible that oxidation may have been far advanced in the eastern highlands of Appalachia before degradation began, and that the transportation of sand and silt from these highlands westward to the Appalachian sea may have been

slow, with frequent intervals of lodgment along the way. Such a condition is suggested by the highly comminuted nature of the material and by the broken and fragmentary character of such plant fossils as now remain.

SOURCE ROCKS

The scarcity of organic matter, both of vegetable and animal origin, and the oxidized character of the sediments in the Catskill series are so pronounced as to cast much doubt on the idea that any large amount of oil may have originated in these beds. On the other hand, the different groups of the Upper Devonian farther down, including the Chemung, Portage, Genesee, Hamilton, and Marcellus, are generally plentifully marine, and some of these groups are even noticeably bituminous in character, although they contain few porous horizons capable of holding large quantities of oil. The Chemung and Portage also sustained rather luxuriant vegetation, as is evident in the Tygart Valley of Randolph County, where Reger has recently measured trees that range from 1 to 4 feet in diameter, as will be discussed in a forthcoming publication. It is easy to believe that oil and gas could have originated in these lower shales, being gradually pushed upward into the more porous Catskill by increasing superincumbent weight.

RELATION OF ACCUMULATION TO STRUCTURE

REGIONAL

As in many other major petroliferous provinces of the world, the oil of the Appalachian region occurs in the minor structures of a vast geosyncline where there was a long era during which the accumulation and preservation of organic matter were scarcely interrupted.

LOCAL

Locally, the oil of the Copley pool occurs in a comparatively deep syncline in sands which carry no connate water. It is worthy of note that gas is found not only in the anticlines on either side but also along the axis of the syncline for many miles after it begins its rather constant rise 2 miles northeast of Copley. Such instances of accumulation are common in the non-hydrous sands of the Appalachian fields, and illustrate the anticlinal, or gravity, theory of the oil and gas accumulation as advanced by White[1] many years ago.

MIGRATION

There is little evidence for belief that the oil at Copley has traveled far in any lateral direction, since on the west it is cut off from the main Appalachian Geosyncline by the Chestnut Ridge Anticline, and on the east by the Orlando Anticline and by outcrops farther on. It is rather to be believed that upward migration from the deeper Devonian shales was the main movement, and that the oil found lodgment in the low part of the synclinal basin, while the gas continued laterally toward the adjacent anticlines and toward the higher structure of the syncline northeastward.

[1] I. C. White, "The Geology of Natural Gas," *Science*, June 26, 1885; republished in "Oil and Gas," *W. Va. Geol. Survey*, Vol. I a (1904), pp. 49–52.

OIL

PHYSICAL AND CHEMICAL CHARACTER

Owing to the fact that the sand oils of West Virginia show little variation in physical and chemical character from pool to pool, being all of paraffin base and practically free from sulphur, and being usually turned into trunk pipe lines without attempt at segregation, numerous pools of considerable size have delivered their production for many years without published analyses of the oil. This appears to have been the case at Copley, where no analyses are available. In the Alvy pool of Tyler County, however, 30 miles or more farther north, Day[1] gives an analysis of Gordon sand oil that probably approximates the nature of the Copley pool. This sample was collected by M. J. Munn from the J. F. Ingraham lot well No. 1 at a depth of 2,670 feet, with analysis as follows:

ANALYSIS OF OIL FROM ALVY POOL, TYLER COUNTY

Physical properties:		
Specific gravity at 60° F.		0.8078
Baumé gravity at 60° F.		43.3
Color		Medium amber
Odor		Like Pa. oil
Distillation by Engler's method:		
Begins to boil at		70° C.
	Cubic Centimeters	Specific Gravity
By Volume:		
To 150° C.	14.0	0.7163
150°–300° C.	38.0	0.7840
Residuum	46.7	0.8621
Total	98.7	
		Percentage
Sulphur		....
Paraffin		6.11
Asphalt		0.00
Unsaturated hydrocarbons, crude		7.6
Unsaturated hydrocarbons, 150°–300° C		4.0

The analysis of this oil in Tyler County compares favorably with nearly all other sand oils in West Virginia and is probably fairly representative of the Gordon and other Catskill series oils at Copley.

OIL PRODUCTION

Figures on oil production are not available for the entire pool, since various operations are involved, some of which are now abandoned. C. B. Turner, general manager of the South Penn Oil Company, however, has very kindly furnished the complete production record of the Michael Copley Heirs lease, as herewith reproduced in Table II.

[1] David T. Day, "Mineral Resources," *U. S. Geol. Survey*, Part II (1909), pp. 424–25.

TABLE II

PRODUCTION RECORD OF MICHAEL COPLEY HEIRS 128-ACRE LEASE, AS FURNISHED BY SOUTH PENN OIL COMPANY

A. DEPTH AND INITIAL PRODUCTION OF EIGHT WELLS

Well No.		Depth (in Feet)	Sand	Initial Production First 24 Hrs.
1	Completed 9/13/1900	2,530	Stray	5,000 bbls.
2	Completed 12/ 6/1900	2,671	Gordon	20 bbls.
3	Completed 1/18/1901	2,625	Gordon	600 bbls.
4	Not Drilled	.....	.....	.....
5	Completed 5/27/1901	2,880	Fifth	Dry and Abandoned
6	Completed 9/22/1919	2,688	Gordon	2 bbls.
7	Completed 9/ 2/1920	2,970	Gordon	15 bbls.
8	Completed 12/20/1920	3,100	Fifth	Dry and Abandoned

B. LOG OF WELL NO. 1

Log of Well No. 1	Depth (in Feet)
Pittsburgh Coal	140
Pencil Cave	1,775–1,800
Big Lime	1,800–1,895
Big Injun	1,895–2,025
Stray	2,512–2,524
Oil	2,519
Gordon	2,530
Total depth	2,530

C. PRODUCTION*

Well No.	Year	Barrels Produced (7/8)	Royalty (1/8)	Total Production	Daily Average Production for Lease	Daily Average Production per Well
		Bbls.	Bbls.	Bbls.	Bbls.	Bbls.
1–2	1900	153,103.43	21,871.92	174,975.35	1,590.69	795.34
1–2–3	1901	27,072.74	3,867.53	30,940.27	84.77	28.26
1–2–3	1902	3,498.27	499.75	3,998.02	10.95	3.65
1–2–3	1903	1,913.84	273.41	2,187.25	5.99	2.00
1–2–3	1904	1,018.94	145.56	1,164.50	3.19	1.06
1–2–3	1905	2,290.54	327.22	2,617.76	7.17	2.39
1–2–3	1906	2,523.14	360.45	2,883.59	7.90	2.63
1–2–3	1907	1,970.09	281.44	2,251.53	6.17	2.06
1–2–3	1908	2,271.05	324.44	2,595.49	7.11	2.37
1–2–3	1909	1,183.17	169.02	1,352.19	3.70	1.23
1–2–3	1910	1,228.32	175.47	1,403.79	3.85	1.28
1–2–3	1911	1,116.66	159.52	1,276.18	3.50	1.17
1–2–3	1912	1,024.41	146.34	1,170.75	3.21	1.07
1–2–3	1913	1,174.47	167.78	1,342.25	3.68	1.23
1–2–3	1914	1,153.48	164.78	1,318.26	3.61	1.20
1–2–3	1915	1,070.20	152.89	1,223.09	3.35	1.12
1–2–3	1916	1,272.46	181.78	1,454.24	3.98	1.33
1–2–3	1917	1,360.59	194.37	1,554.96	4.26	1.42
1–2–3	1918	1,761.77	251.68	2,013.45	5.52	1.84
1–2–3–6	1919	1,741.59	248.80	1,990.39	5.45	1.36
1–2–3–6–7	1920	2,867.65	409.66	3,277.31	8.98	2.24
1–2–3–6–7	1921	2,058.00	294.00	2,352.00	6.44	1.61
1–2–3–6–7	1922	1,680.40	240.06	1,920.46	5.26	1.31
1–2–3–6–7	1923	1,551.29	221.61	1,772.90	4.86	1.21
1–2–3–6–7	1924	1,466.95	209.56	1,676.51	4.59	1.15
1–2–3–6–7	1925	1,491.09	213.01	1,704.10	4.67	.93
1–2–3–6–7	1926	1,597.56	228.22	1,825.78	5.00	1.00
Totals	.....	222,462.10	31,780.30	254,242.40	26.48	.....

* Estimated recoverable for 7/8 or working interest, 246,500 bbls.

It is evident from Table II that the lease has produced 1,978 barrels of oil per acre, and computing the ultimate gross production as 281,714 barrels on the basis of the estimate furnished, the ultimate total per acre will be 2,201 barrels.

GAS

VOLUME AND PRESSURE

The gas which occurs in abundance on the rising structure northwest, northeast, and southeast of the Copley pool was not exploited to any large extent during the flush years of the pool, but in later years has been intensively produced. Under date of February 7, 1927, John B. Corrin, vice-president and general manager of the Hope Natural Gas Company, discusses it in the following letter:

I have your letter of January 31, asking for certain data in connection with the Copley Oil Pool in Lewis and Gilmer counties, West Virginia. To give you the information requested in detail would require considerable work on the part of our office force, which we are not able to do at this time. However, I wish to state in a general way that the majority of the gas wells situated in the area east of the Copley field were drilled in the years 1909 to 1917. The principal production is from the Gordon Stray and Gordon sands, with an occasional Injun sand well. The average original open flow of the Gordon Stray sand and Gordon sand wells was 1,500,000 cu. ft., with an average rock pressure of 550 pounds. The average rock pressure of the field has declined until today it averages 65 pounds. We have no data available as to the present open flow, nor the daily production of the field.

Like many other oil and gas fields of the state, the production of the Copley pool is largely merged with that of others which pass through the same pipe lines. In the case of gas especially, the saturated strata are continuous with other localities, and hence segregation of production figures would hardly be possible even if full records had been kept.

ABSENCE OF WATER

Like nearly all other pools in which the sands of the Catskill series have been productive in West Virginia and southwestern Pennsylvania, no water is found in the syncline at Copley. In the case of a pool like Copley, where the sands are mostly saturated with oil and gas, this absence of water, although anomalous as compared with many other regions, may be explained as due to displacement, but in localities where there is neither oil nor gas, the content of such pore space as must exist in these barren sands has not been explained to the satisfaction of all. Reeves[1] has suggested that this pore space has been dried out and later occupied by air, but Shaw[2] disputes this idea with the statement that if air existed in the sands, it would be under heavy pressure and would find an outlet when wells were drilled. He suggests further that some water may still remain in the sands; and it would appear to the writer that a more logical explanation would be that a small

[1] Frank Reeves, "The Absence of Water in Certain Sandstones of the Appalachian Oil Fields," *Econ. Geol.*, Vol. 12 (1917), pp. 354–78.

[2] E. W. Shaw, *Econ. Geol.*, Vol. 12 (1917), pp. 610–28.

quantity of water is actually present in these sands, being barely enough to form a seal against the entry of air at outcrops, but insufficient to flow through the sand into a drill hole and insufficient to resist or greatly impede a flow of oil accompanied by gas pressure.

DRILLING AND PRODUCTION METHODS

All drilling in the Copley pool has been done with cable tools and standard 84-foot wood or steel derricks, power being mainly furnished by steam boilers fired by natural gas. For pumping, a central boiler plant is usually placed for each five or six wells, with an engine at each derrick. This method, however, is gradually being displaced throughout West Virginia by gas engines located at each well. Owing to the necessity of re-shooting and cleaning out, the derricks are left at all oil wells, but are generally removed from gas wells after the final cleaning out.

LIFE OF WELLS AND POOL

It is evident from Table II that three wells on the Copley lease, including the discovery well, have pumped more than 25 years; and judged from the fact that a future estimated gross recovery of more than 27,000 barrels is still anticipated from the lease, probably by additional shooting and cleaning out, a future life of perhaps 10 years may be expected. Other properties in the same pool, many of which are still producing, were drilled immediately after the Copley gusher, and hence it would appear that an ultimate life of about 35 years for these sands of the Catskill series may be the rule.

FUTURE DEVELOPMENT

A revival of this old pool through lateral extensions of territory is not probable, since many tests have been drilled in the adjacent parts of the syncline. Scattered wells may be found, but large productive areas may not be expected. Deeper drilling may find additional gas in the sands of the Chemung series along the anticlines and the eastern extension of the syncline, but these lower sands have never produced much oil in West Virginia. It is of course true that the Oriskany sand of the Lower Devonian, and the "Clinton" (White Medina) sand of the Silurian, may be present beneath the Copley pool and may hold oil, but wells must be drilled 7,000–10,000 feet deep to reach them, so that their exploration is probably remote.

THE TRI-COUNTY OIL FIELD OF SOUTHWESTERN INDIANA[1]

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ABSTRACT

The field is located at the juncture of Pike, Gibson, and Warrick counties, Indiana, where the surface formations are of Pennsylvanian age. The regional dip amounts to 35 feet per mile to the southwest, and the collecting structures are mere pimples upon the regional slope. Surface structure does not coincide with subsurface dips, the limestone outcropping in the field showing production coming from a syncline. The oil sand manifests evidences of lens-like accumulation and may be responsible for the arching of the overlying rocks.

The Oakland City sand or the Mooretown sandstone forms the reservoir for petroleum. Gas is entirely lacking; each well had to be shot and put on a pump to secure production. Water is almost a negligible quantity, and the amount handled with the oil is decreasing. The crude is of good quality, green to brown in color, and fairly high in gasoline content. Production is light; consequently development has been slow.

INTRODUCTION

The area under consideration is typical in size and extent of the oil fields of this region. A previous knowledge of conditions and the availability of first-hand information made its selection desirable. The writer takes this opportunity to express his appreciation of the assistance rendered by Mr. W. W. Rogers and Mr. J. O. Rosebaum, of the Consolidated Oil Development Company. Dr. W. N. Logan also deserves much credit for aid in the interpretation of data, especially the correlation of well logs.

HISTORY

The Tri-County oil field is one of several small producing areas in Pike and Gibson counties in southwestern Indiana, and is a fairly typical example of the group. The field is located where Pike, Gibson, and Warrick counties join, in Sections 7, 8, 9, 15, 16 and 17, R. 8 W., T. 3 S. (Fig. 1).

It was strictly a wildcat proposition when drilling started. Two brothers, both drillers, leased the land and commenced drilling the first well. They subsequently entered into partnership with the Consolidated Oil Development Company, providing for operations to continue on about an equal basis. No geological advice was sought or utilized in locating the first few wells, nor were surface indications favorable.

The first location was on the Yaeger farm in Section 9, at a rather high surface elevation. Only a slight showing of oil was obtained in the "brown sand" when the well was completed in August, 1924. An unusual amount of gas was encountered

[1] Presented before the Association at the Tulsa meeting, March 26, 1927.

[2] Introduced by Sidney Powers.

in the higher formations underneath a coal bed, probably Coal IV, according to the system of numbering in Indiana.

The second well drilled, No. 1, on the Raeburn lease, gave the first commercial production. It came in at 15 barrels a day during November of the same year. The Ohio Oil Company secured leases upon the northwest quarter of Section 16 and drilled five wells altogether, one of which made 75 barrels the first day. Gradual development has ensued, in keeping with the light production of the field.

FIG. 1.—Spot map showing location of field within the state.

PHYSIOGRAPHY

The field lies a few miles within the western edge of the driftless area of Indiana, so that the surface has not been altered by glaciation. The term "gently rolling" adequately describes the region, and the fact that it is included in Fenneman's physiographic division, "The Aggraded Valley Section," shows the nature of the drainage. Most of the bed rock is soft Pennsylvanian shale or sandstone which has offered little resistance to erosional degradation. As a result a homogeneous plain has been formed parallel to Wabash River more or less regardless of glaciation. The relief is generally moderate and gentle, but in many places the uplands rise abruptly from the wide, level stream valleys. A few notable examples occur where isolated hills of bed rock, some of which are more than 100 feet in height, stand out prominently with respect to the surrounding alluvial or glacial plain. Few places exceed 700 feet in elevation, and the general level is near 500 feet.[1]

STRATIGRAPHY

All of the exposed formations in this district are of Pennsylvanian age, either Alleghenian or post-Alleghenian. Most of the rocks are shales and sandstones, interbedded with a few limestones and coal beds. Coal V (of Indiana) outcrops a few miles to the east, and numbers VI and VII appear south and west of the oil field. Two or three limestones of local extent occur in this part of Indiana, only one of which has been important enough to be named and mapped. One such limestone outcrops within the Tri-County field and has been used as a datum plane for surface mapping. Where typically developed it occurs in two beds separated by 5

[1] C. A. Malott, "Physiography of Indiana," *Indiana Handbook of Geology*, 1922.

to 10 feet of shale. Both strata range from 5 to 10 feet in thickness and assume a reddish-brown color where weathered.

The Somerville or West Franklin limestone is stratigraphically about 60 feet above the first-mentioned limestone, but is very similar in appearance. It constitutes the most reliable datum plane for surface mapping for many miles to the southwest, due to its proximity to the surface and consequently plentiful outcrops.

Coal V of the Petersburg group outcrops a few miles east of the field and can be used as a horizon for structural control. For such indications, it is probably the most reliable of any of the coal beds in the state. Most of the collecting structures found in Dubois and Pike counties have been defined upon this stratum. Almost every section in each county has been tested for coal, and these drilling records constitute the chief source of information as to the depth and thickness of Coal V. No coal bed is reliable as a basis for determining subsurface structural conditions, but as in many places the irregularities of this one are depicted in a general way on the formations beneath, it is widely used in southern Indiana.

An erosional unconformity exists between the Pennsylvanian and the Mississippian in Indiana, causing the Mansfield sandstone, the basal member of the Pennsylvanian, to overlap many of the Chester formations and even rocks as old as the Devonian. Where the Mansfield is absent, depressions in the eroded surface of the Mississippian are occupied by shales. In most places the Mansfield carries water under pressure and ordinarily completely fills wells drilled into it. Typically it is a massive, poorly cemented sandstone, of sufficient porosity to contain much water. It ranges in thickness from 50 to 300 feet. Conglomeratic phases commonly comprise the lower part, with the size of the grains decreasing in the upper parts.

The Chester of the Mississippian is represented in Indiana by a series of clastics containing a few outstanding limestones. Only a few horizons are conspicuous or persistent in well records, and these occur in the lower group of the Chester. The upper Chester is principally shale and exhibits no marked uniformity of characteristics, though a few units may be identified in the middle part. The following are the more important.

The Tar Springs sandstone may be identified in places and occurs at some points directly under the Mansfield sandstone. Except for the Golconda limestone and possibly the Cypress sandstone, it is the only recognizable unit of the upper and middle Chester. Typically it is fine-grained, massively bedded, and poorly cemented. In many well logs its contact with the superjacent Mansfield is not clearly defined. As a water-bearing horizon it ranks second only to the Mansfield.

The Beech Creek limestone of the lower Chester, called the "Little lime" by drillers, is used for correlation purposes. It is normally 15 or 20 feet thick near its outcrop, but thickens to 40 feet in places, according to the well records. The Beech Creek is seldom broken by partings and is characteristically overlain by the Cypress sandstone.

Lower down, a stratum called by drillers "red rock" is a depth marker. It probably correlates with the Reelsville limestone in the lower Chester. Character-

istically it is reddish-brown in color and 3 to 5 feet in thickness, but it may change into shale or become so thin as to be passed unrecognized. A short distance below the Reelsville horizon a massive limestone is encountered which represents the Beaver Bend formation. Where it outcrops to the east, its thickness is normally about 15 feet, but well records reveal 40 to 50 feet of it. It is gray in color and rarely absent, and, coming just above the Mooretown sandstone, forms a satisfactory datum plane for subsurface structural determinations.[1] Figure 2 shows a general section for the field, with the approximate depths of the formations.

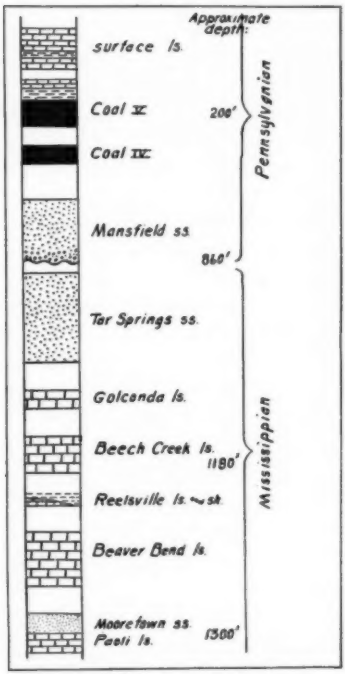

FIG. 2.—Generalized section of the Pennsylvanian and upper Mississippian in the Tri-County field, showing the more easily recognizable horizons. Thicknesses of formations greatly exaggerated. Approximate depth in feet.

Throughout the field, only the Oakland City sand is productive. It correlates with or comprises a part of the Mooretown sandstone of the general section. Another sand, called the Brown sand, is reached a short distance below the Oakland City horizon. The Brown sand is more commonly a dolomite or porous limestone than a true sandstone, and is contained within the Paoli formation of the geologic column. Excellent showings have been found in the latter sand, but there is no commercial production to date in this field.

GENERAL STRUCTURAL CONDITIONS

The Eastern Interior Coal Basin into which the rocks dip from the Cincinnati Arch forms the major structural feature of southwestern Indiana. The basin includes south-central Illinois, northwestern Kentucky, and southwestern Indiana. The regional dip in southern Indiana is determined by the extension of the formations from the Cincinnati Uplift and its flanks into the coal basin. The inclination of the rocks is gentle or lacking near the crest of the arch in eastern Indiana and increases in gradient toward the basin. The belts of outcrop of the formations in the southern part of the state extend generally north and south, as the arch has been truncated, exposing the edges of the successive formations. The region under consideration lies in the most

[1] C. A. Malott, "The Upper Chester of Indiana," *Proc. Indiana Acad. Sci.*, 1925.
W. N. Logan, "Geological Conditions in the Oil Fields of Southwestern Indiana," *Ind. State Dept. Cons., Div. Geology*, 1924.

westerly of these belts, on the east slope of the coal basin, where the rocks dip under to the west at the rate of 35 feet per mile. The surface formations are of Pennsylvanian age, consisting of sandstones, shales, and thin limestones intercalated with beds of coal. The type of topography formed by these non-resistant rocks has been described.

The local areal geology is complicated and not thoroughly worked out. Thin limestones and coal beds, local in extent and interbedded with varying thicknesses of shales and sandstones, make correlation difficult without intensive study. Cross-bedding exists within the sandstones, and likewise variations in thickness and changes of facies occur within short distances. Consequently surface mapping to determine structural conditions, especially where correlations are involved, is hazardous. Surface and subsurface structures seldom conform to each other except in a general way.

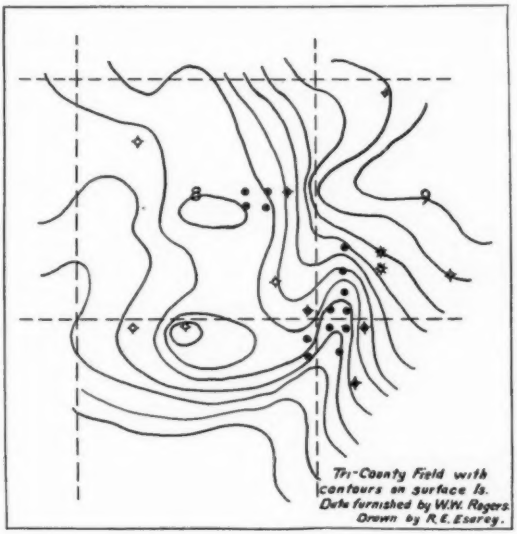

FIG. 3.—Contour interval, 5 feet. Notice producing wells located in a syncline. Compare with Figure 4.

Where a coal bed is used for a datum plane, in many places the higher levels between local coal basins may be depicted on a structural map without any actual structural deformation existing. Very promising structures outlined on coal beds have been accounted for by abnormal thicknesses of sandstone under the coal. In places the thickness of the coal bed will help determine the presence of coal basins or actual structure. In addition to the Somerville or West Franklin limestone there are other local limestones of limited extent which may be used for surface mapping. One of these extends through the Tri-County field. The accompanying map shows the discrepancies between surface and subsurface mapping in this field. (Fig. 3. Compare with Fig. 4, where the contours are drawn upon the oil sand.)

The Somerville occurs in two beds separated by an interval of shale which may locally thin and thicken. The beds converge to form one bed near Ohio River, and at some points the upper bed has been removed by erosion. Care must be exercised in choosing the same bed for a datum plane in each case and noting the shale

interval. It seems probable that a limestone deposited upon a shale or above a coal bed would settle with the underlying formation or even compress the shale or coal in such a manner as to indicate pronounced dips where none occurs. The surface limestone in the Tri-County field fulfils these conditions by evincing structure which does not "hold up" on the lower formation.

The predominating type of fold in this part of Indiana is the small anticline. Terraces or monoclinal structures are also common, but are possibly depositional features rather than structural.

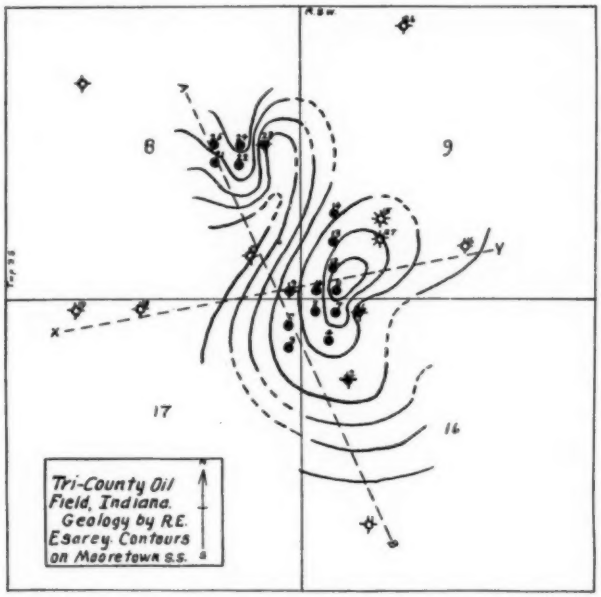

FIG. 4.—Contour lines drawn upon the top of the Oakland City sand or the Mooretown. Interval, 5 feet. Notice location of producing wells on structure.

Most terraces and anticlines so far discovered have been small in size and extent, amounting to mere pimples on the regional slopes. Productive areas upon these structures vary from a few acres in size to 160 acres, supporting from 3 to 40 wells. In some fields many small anticlines are grouped together, that is, a succession of folds occurs, separated by synclines or narrow, non-productive belts, making the aggregated producing acreage fairly respectable in size.

RELATION OF ACCUMULATION TO STRUCTURE

In most of the fields throughout southwestern Indiana the major part of the oil accumulates in the southwestern part of the collecting structure. The direction of the regional dip would tend to make this a normal condition. Gas is generally present near the crest of the anticlines with the oil on the flanks.

Only small amounts of gas were encountered in the Tri-County field, not enough in all the wells to furnish power for the pumping stations. Wells Nos. 15 and 27 produced small volumes of gas when brought in, but no constant flow occurred, nor was the volume large enough to build up a measurable pressure. The total absence of gas appears unusual, as near-by fields have produced it in large quantities. The drillers report from 5 to 20 feet of dark shale everywhere overlying the oil sand, thus preventing the easy escape of gas from the structure, if any has ever been present. Crude from the field has a Baumé gravity of about 34 degrees, a brownish-green color, and, from its odor, seems to be a live, fresh oil. However, none of the wells were free-flowing or exhibited evidences of gas pressure. Even ordinary water pressure is lacking, so that the gas, if originally present, might have escaped up the regional dip. The anticline is small in size and may not have afforded a sufficient trap to collect and retain gas in measurable quantities. A few miles to the west, near Somerville, Indiana, is a fairly large anticline which has been found to contain millions of cubic feet of gas, but no oil in commercial quantities. The gas collecting in such a quantity may have completely or almost completely filled the structure and forced the migration of oil up the regional dip toward the field under discussion. The small size of the anticline in the Tri-County field remains the most potent factor in explaining the absence of gas, however.

Oil production has occurred on the top part as well as the south and west parts, since gas is not present. The largest well, No. 8 (Fig. 4), was brought in by the Ohio Oil Company with an initial production of about 75 barrels per day. Well No. 10, an offset one location north of the foregoing well, started at 50 barrels per day. Offset wells to the east of each of these produced similar amounts, when first put to pumping. As the farthest north well in the pool came in at 10 barrels, the limit of production in this direction has not been definitely determined. On the extreme southwestern edge of the field the wells had low initial production, but are profitable to operate. The amount of water pumped with the oil is greatest in these latter wells.

A second collecting structure, seemingly a terrace, furnishes production for the northern part of the field. Only four producing wells have been drilled upon it, so that to date the exact nature of it has not been revealed. Figure 3 shows the trend of surface structure, however. Additional wells are being started which will test out the productive limits of this reservoir.

Water conditions are abnormal in that very little water is present; certainly not enough to interfere with drilling or production. No wells brought in had heavy gas or water pressure. Most of them filled up with water and oil for only a few hundred feet after shooting. The column of fluid is easily pumped down and does not refill the casing rapidly. According to the field superintendent in charge, the amount of water handled since the wells came in has materially decreased. Evidently underground water circulation is obstructed, or very meager, throughout the sand.

Figures 5 and 6 are cross-sections of the collecting structure along the dotted lines in Figure 4. The first is along the strike, *A* to *B*, and the other extends parallel

to the direction of dip, *X* to *Y*. In Figure 5, the Beech Creek limestone shows a more pronounced folding than other horizons, but in other respects is similar to Figure 4. Coal V indicates a decided syncline in the center of the field which no other stratum follows. The writer believes that most of the irregularities and variations in the cross-sections are due to differences in thickness of the formations or intervals—depositional rather than dynamic. The correlations are the best possible under the conditions, as a few of the records were poorly kept. Figure 6 reveals only a monoclinal structure on the Beech Creek limestone and a very slight reversal

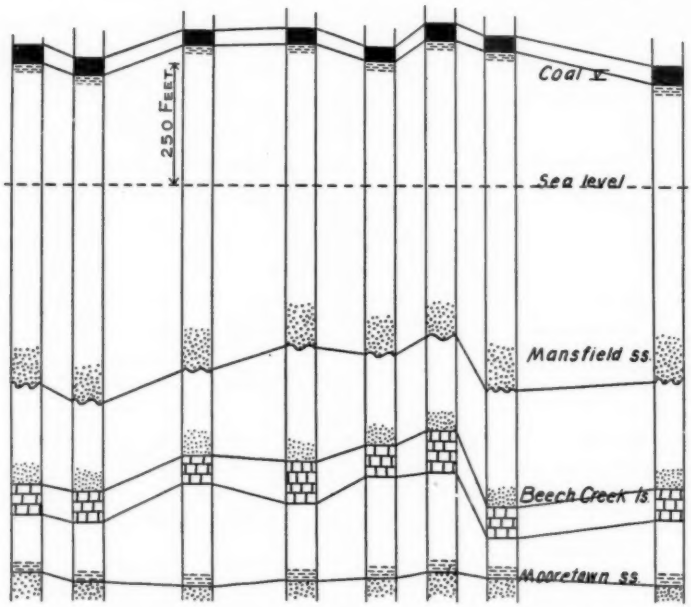

FIG. 5.—Cross-section along the line *A–B* in Figure 4

on Coal V. The oil sand shows the greatest east dip, which suggests accumulation in a lens of sandstone.

RESERVOIR ROCKS

The Oakland City oil horizon or the Mooretown sandstone averages about 20 feet in thickness throughout this field. Where not colored with oil, it is white to gray in color, which, with its hardness and fineness of grain, makes it appear similar to a limestone. The productive part of the sand begins about two feet "in" and extends nearly to the base. No particular stratum is more highly saturated than another, the samples indicating a uniform vertical distribution of oil. Few wells have continued through the sand, as the lower few feet are seldom productive and water is commonly present in the limestone beneath. Shooting is essential to production.

The thickness of the sand is different in different wells, and the oil content varies with the porosity of the sand, and the porosity with the thickness. For example, in well No. 24, 26 feet of porous well-saturated sand are found, while in well No. 23, only 600 feet away, the sand is only 7 feet thick and is replaced largely by shale, in addition to being finer-grained and better cemented. At other places, especially down the dip of the structure, wells have struck slight thicknesses of sand,

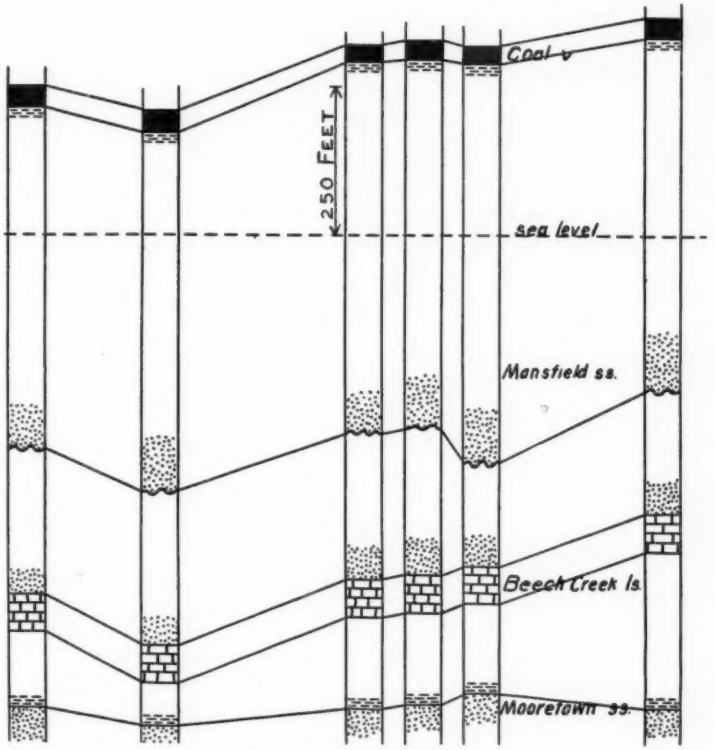

FIG. 6.—Section along line *X–Y* in Figure 4

with shale occupying the remainder of the normal interval. No. 6 has only 9 feet of producing sand, which is overlain by "shelly" sandstone grading rapidly into true limestone. Well No. 7, just west of No. 6, has 21 feet of saturated sand and is one of the best producers in the pool. Again, No. 17 passed through only 11 feet of sand, which is below normal. Complete records of the thickness and samples of the sand are not available, so that a cross-section or study of conditions is not possible, but the foregoing illustrations point to a lens-like accumulation of sand forming the oil reservoir.

The uppermost two feet of the Mooretown are seldom productive or even saturated with oil. The bulk of this stratum is fine sand intermixed with some shale and pyrite particles. The grains are mostly transparent quartz, uniformly of small size and subangular to well rounded in shape. A small amount of calcium carbonate is present, which acts as a cementing agent. The absence of iron oxide is conspicuous, and the heavy metallic substances are not plentiful. The many particles and masses of pyrite merit discussion on account of their nature and abundance. The pyrite serves as a cementing substance for grains of sand and shale, but it likewise composes the major part of the masses. In size the concretion-like masses range from one thirty-second part of an inch to three-fourths of an inch in diameter, but appear uniform in composition. In the larger masses the inclosed sand grains are well rounded and lend to the body as a whole the appearance of a well-cemented conglomerate. The number of masses and the amount of pyrite diminish with depth in the sand, according to available samples. However, the coloring imparted by the crude oil may obscure the pyrite.

Uncontaminated samples of water from the oil sand or the limestone beneath are not available at present. Its exact composition is therefore not known, but the chief mineral in solution is sodium chloride. The data point to the following explanation of the presence of iron sulphide within the sandstone. Ferrous sulphate in the water is reduced by sulphur bacteria, producing hydrogen sulphide. The latter, being a strong reducing agent, in turn precipitates the iron compounds in solution in the water as iron sulphides. Other explanations might appear with a more detailed knowledge of sand conditions.

The porosity of the Mooretown sand as a whole is very low for a "reservoir rock." Actual pore space is slightly under five per cent, as an average, from all samples collected, due to the irregular shape of the particles, the presence of some clay and calcium carbonate, and the fineness of grain. The character of the sediments indicates that deposition took place in relatively quiet waters away from the shore. Since the Mooretown overlies limestone and grades into it, this would certainly be true of the lower part. The central 20 feet is almost a pure sandstone, of greater porosity and coarser grain, thus more nearly approaching a shore or strand-line deposit. The production of oil comes almost exclusively from this part. The uppermost 3 feet again become fine-grained and well cemented with calcium carbonate. In addition, shale everywhere overlies the Mooretown, indicating that deep or quiet water conditions prevailed during the deposition of the upper part.

The character of the oil remains uniform throughout the field. Samples were taken from the different leases and each showed the same gravity, sulphur content, and fractionation percentages. The Baumé gravity is 34, sulphur content less than 0.5 per cent, the gasoline fraction up to 150° C., 20.3 per cent, and the burning-oil fraction up to 275° C., 28 per cent. Production records for each individual well have not been kept and lease records do not show exact dates and amounts of new production added. Hence a graphic representation of production would be of little value.

SOME NOTES ON THE GEOLOGY OF THE SOUTH SAN JOAQUIN VALLEY, CALIFORNIA[1]

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Los Angeles California

ABSTRACT

The paper discusses the importance of the overlaps in the southern part of the San Joaquin valley. Two of these overlaps are of remarkable magnitude: one existing at the base of the Vaqueros (lower Miocene) and the other at the base of the Santa Margarita (uppermost Miocene).

Each overlap was preceded by an intense folding, and the structural features in these different periods of folding are evidently independent of each other.

This is well illustrated in the lower Santiago Canyon in the San Emigdio district where Vaqueros beds are folded into an anticline that is not reflected in an underlying, apparently monoclinal, series of Oligocene beds. Not far from this locality a broad syncline of Etchegoin (Pliocene) overlies vertical beds of Vaqueros.

The great overlap of the Santa Margarita and Etchegoin brings these formations into contact with all the older ones. They are therefore able to accumulate the oil produced in different strata of the older rocks. This may explain the great quantities of oil now present in the Etchegoin, without making it necessary to admit that the oil accumulated by migration over long distance.

As a result of extensive detailed geological mapping in the southern part of the San Joaquin Valley, the writer concludes that overlaps in several of the formations play a very important part in the geology of the southern part of the valley. These overlaps have, of course, been recognized by earlier writers, but their remarkable magnitude does not seem to have been fully realized.

The writer is indebted to Professor Bruce L. Clark for the determination of fossils and for suggestions made at various times in the field. He would also express his thanks to Mr. E. F. Davis, of the Shell Company, for suggestions during the progress of this work.

The two overlaps which are of major importance occur (1) at the base of the Vaqueros formation (lower Miocene), or, where this formation is missing, at the base of the Temblor or the Monterey (middle Miocene), and (2) at the base of the Santa Margarita formation (upper Miocene). Where the Santa Margarita formation is not present the overlap exists at the base of the Etchegoin formation (Pliocene). In addition, there is without doubt an important unconformity with overlap between the Paso Robles (upper Pliocene) and the Etchegoin formations.

The evidence for the Vaqueros overlap is found in the San Emigdio Mountains of Kern County, where the granite of these mountains ends to the west near Santiago Creek. Here the Vaqueros rests directly on the granite, forming an anticline. An isolated area of the Vaqueros entirely surrounded by granite and containing andesites at the base is found on top of the ridge near the west end of the granite. Another isolated area of sandstone and andesite is found farther to the east on the

[1] Received by the editor March 21, 1927.

[2] Shell Company of California, Higgins Building, Los Angeles, California.

granite ridge west of San Emigdio Mountain. The structural features in the Vaqueros are independent of the structural features in the Eocene and Oligocene. This is well illustrated in exposures between Muddy Creek and Santiago Canyon in the San Emigdio district, where the Vaqueros is folded into an anticline that is not reflected in the underlying northward-dipping series of Oligocene beds.

To the north, in the area between Cholame Valley and the Devil's Den, the Vaqueros is absent. Here the sandstone series, called Vaqueros on the United States Geological Survey maps, is of Temblor (middle Miocene) age. These sandstones contain large numbers of *Pecten andersoni* and *Turitella ocoyana*, considered to be type fossils of the Temblor. South of Antelope Valley, in upper Franciscan Creek, the Temblor sandstones contain numbers of *Tivela diabloensis* Clark. This fossil was previously considered to be restricted to the Santa Margarita.

The Temblor in the Devil's Den region lies directly on both the Cretaceous and the Eocene. The Geological Survey maps show here Kreyenhagen shales, referred to the Oligocene, but it is probable that these beds are of Eocene rather than Oligocene age, since a bed in the middle of the Kreyenhagen shales near Wagon Wheel Mountain, southeast of the Devil's Den region, contains numerous specimens of a *Corbis* similar to *Corbis diegoensis Dickerson* in the Domengine (Eocene) formation of the San Emigdio Mountains.

In the Cholame area, San Luis Obispo County, Monterey sandstones rest both on the Cretaceous and on the Franciscan strata. The importance of the Monterey transgression in this region is shown by the fact that near Little Avenal Canyon, Monterey sandstones rest on a great mass of Cretaceous sediments several thousand feet thick. Only about two miles to the south, near Red Rock Canyon, the Monterey lies directly on the Franciscan and the Cretaceous is entirely absent.

The important overlap of the Santa Margarita is very evident in the Devil's Den region in northern Kern County. Previously the white shales in the northern part of the Devil's Den region and in the Pyramid Hills south of Dagany Gap were called Monterey. A portion of this shale south of the Dagany Gap is really of Monterey age. The part referable to the Monterey consists of soft brown, rather siliceous shales, containing many layers of yellow-weathering limestone. This shale appears in the center of the anticline in the Pyramid Hills south of Dagany Gap. In this area the more resistant Santa Margarita shale forms the high hills, while the softer Monterey shale is found only in the depressions.

Detailed mapping of the contact between the yellow-weathering Monterey and the white siliceous shales of the Santa Margarita shows a progressive overlap of the Monterey by the Santa Margarita. The prominent fossil reef in the Temblor at the base of the Monterey shale north of the Devil's Den oil field is gradually approached by the Monterey due to this overlap.

That these white shales can be referred to the Santa Margarita is certain, for they form the direct continuation of the Santa Margarita shale of Coalinga and of the Tent Hills. In the Tent Hills the Santa Margarita is found lying directly on the Cretaceous, and in the southern part of these hills, near the base of the shale, a fossil reef contains *Phacoides annulata* Conrad, a distinctive fossil.

The Monterey and Santa Margarita overlaps are both very apparent in the northwestern portion of the Devil's Den region. The base of the small outcrop of

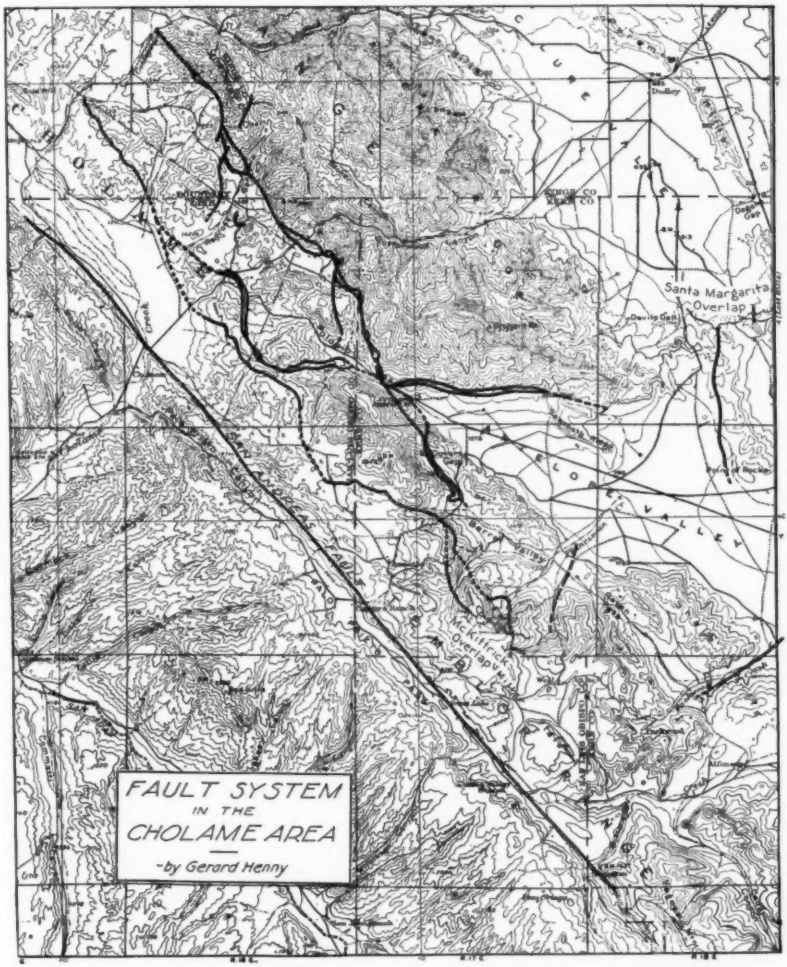

FIG. 1.—Fault system in the Cholame area. Topographic contour interval 100 feet. Approximate scale, 1⅞ inches=6 miles.

Monterey shale here comprises a fossiliferous sandstone reef. This lies to the north on Eocene sandstone, but toward the south it rests directly upon the Cretaceous where the reef contains a conglomerate in which are angular blocks of Cretaceous sandstone. The Santa Margarita shale lies on the Monterey shale,

which, on the Geological Survey maps, was indicated as Cretaceous. Toward the south the Santa Margarita again rests directly on the Cretaceous. Apparently the Cretaceous formed the coast in both the Monterey and Santa Margarita seas. The existence of these overlaps has been previously overlooked, the structural relations being interpreted by faulting.

Another proof of the importance of the Santa Margarita overlap lies in the fact that in the northern part of the Devil's Den the Santa Margarita formation lies undisturbed across an important north-south fault in the older formations. This fault separates the Eocene to the west from the Cretaceous to the east. The Devil's Den fault, which is thus shown to be older than the Santa Margarita, is probably of the same age as the large faults in the Cholame area and the faults south and north of Antelope Valley. Two of these faults are indicated on English's map, one lying north of Antelope Valley in the Cretaceous, and one south of this valley, starting in Barrel Valley, both converging and intersecting east of Polonio Pass. Two more of these faults exist to the west. They contain fragments of the Franciscan series, particularly serpentine.

The writer is convinced that all of the serpentine of the Cholame area is of Franciscan age, and that none of it is intrusive into the Cretaceous. This is a different interpretation from that of English, who shows the serpentine near Parkfield as intrusive into the Cretaceous. The serpentine is exceedingly plastic in its character and was probably squeezed into the faults in the same manner in which salt is forced into salt domes and salt anticlines.

The four major faults just mentioned are rather irregular in their course, but have a general extension northwest and southeast, being considered to be of pre-Santa Margarita age. They are themselves displaced by cross-faults having a north-south trend. These cross-faults cut the major faults and folds in the Monterey and earlier formations in such a manner that all the structures are offset toward the south on the east side of each cross-fault. They are, of course, younger than the major faults, and are probably the result of tensional stresses occasioned by horizontal movements along the San Andreas fault. The four major faults, on the contrary, are considered to be the result of vertical displacement. It was suggested that their age might be pre-Santa Margarita. This could not be definitely proved in the area examined by the author, this formation being absent near the faults. The McKittrick formation, however, covers them undisturbed, whereas the San Andreas fault is situated in a typical rift valley in this same formation. It is obvious that the San Andreas Rift has a different origin and age because it forms a nearly straight line, in contrast to the four other major faults, which show a rather sinuous course.

In the area between Devil's Den and Cholame Valley at least ten thousand feet of Cretaceous sediments are present, as measured along Little Avenal Canyon. It is a remarkable fact that in a distance of two miles west of this Cretaceous area along the border of Cholame Valley it is entirely missing between the Franciscan and the Monterey. The writer, therefore, feels certain that in pre-Monterey time a high mountain range must have existed through folding in the Cholame Valley.

The Cretaceous must have been removed by erosion and the topography leveled before the deposition of the early Miocene. After Monterey time there was a period of folding, and in that general period also the four major faults before mentioned were formed. The east border of the Cholame Valley and the region south of the Antelope Valley were depressed with reference to the large Cretaceous area to the east and north.

Before Santa Margarita time another period of erosion occurred, and after the deposition of the Santa Margarita and the McKittrick there was another period of folding. This diastrophic movement seems to have been less intense than the post-Monterey disturbance, but of course it accentuated the dips in the Monterey, causing a slight unconformity to exist between the Santa Margarita and the Etchegoin, and also between the Etchegoin and the Paso Robles.

At last the San Andreas fault was initiated, and the important horizontal movements associated with this fault were also the cause of the numerous cross-faults that displace the four major faults before mentioned.

In the San Emigdio Mountains the existence of the Santa Margarita formation could not be proved. Only in one place on the ridge at the west side of the principal canyon between San Emigdio and Muddy Creek a small amount of white shale was found below the Etchegoin. This shale may possibly be of Santa Margarita age.

The overlap of the Etchegoin is very apparent in this region. A broad syncline and an anticline in the Etchegoin and Paso Robles occur near the border of the San Joaquin Valley, apparently on a monoclinal series of older formations which dip very steeply. Here also the overlap of the Paso Robles on the Etchegoin is quite conspicuous.

In Pleitito Canyon, the next canyon east of San Emigdio Creek, Pack shows on his map a lens of Monterey shale surrounded by Etchegoin. This interpretation is not correct.

The Monterey in this part of the San Emigdio Mountains consists of a great thickness of conglomerate, green and red shales, and clays with white shale at the base of the formation and at the top.

The lens of Monterey shale in lower Pleitito Canyon is part of the upper white shale of the Monterey, and the reddish clays and conglomerates to the south of the white shale are also of Monterey age, forming a normal series of Monterey lying in stratigraphical succession on the Vaqueros. The white shale is covered to the north by the Etchegoin, which overlaps the white shale toward the west. In this same direction both the Etchegoin and the Monterey are again overlapped by the Paso Robles formation, which comes in direct contact with the Vaqueros. The Etchegoin and Paso Robles here stand nearly vertical. It is not necessary to explain by faulting the relations in this part of the area.

The great overlap of Etchegoin and Santa Margarita formations suggests a long period of folding and erosion before their deposition. Since they overlie all the older formations unconformably, they are in a position to be the reservoir for nearly all the oil produced in the different strata of the older rocks. This may explain the great quantity of oil in the Etchegoin.

NOTES ON THE McKITTRICK, CALIFORNIA, OIL FIELD[1]

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ABSTRACT

In 1907 Arnold and Johnson published on this field, showing a low-angle overthrust fault as the controlling structural feature. Their description has been widely quoted in subsequent literature, and this structure will continue to be referred to as one of the few oil-bearing structures of that type. It therefore seems desirable to have some fresh word on the subject, and particularly whether the last twenty years has brought forth facts which make the original description inaccurate or misleading. Detailed areal mapping by the writer indicates that there is a low-angle overthrust fault present, but that it is complicated by many minor thrusts, and by a series of steep hade strike faults. The latter, rather than the overthrust, determine the position and structural relationship of the productive sand bodies, though the overthrust shale does at some places form a roof over the productive sands.

In 1910 Arnold and Johnson published *U. S. Geological Survey Bulletin No. 406*, in which the McKittrick as well as other fields of the Sunset-Midway region were described in detail. Since that time there has been practically nothing published on the geology of the McKittrick field, other than a small paper by Clark Gester, calling attention to the significance of the presence of a small area of outcrop of Etchegoin formation a short distance south of the field. At the time that Arnold and Johnson published, the McKittrick field was well past its peak, and there has been little incentive to further study of the very complex structure that is present within this area. Geologists for the Associated Oil Company, which holds the greater part of the productive land, have made some subsurface studies, and the writer and others have mapped the surface in more or less detail. The general result of such studies is that a few empirical rules governing the productive limits and the presence of bottom- and edge-water have been developed, but little has been added to our knowledge of conditions controlling oil accumulation. The main feature of structure (overthrust fault) described by Arnold and Johnson still stands as correct, and the details of structure are so complicated that, while they may not have been correctly determined by Arnold and Johnson, later workers are not able to substitute anything much more definite.

For those not immediately familiar with California stratigraphy, the following is a brief description of the formations important with relation to oil in this part of the San Joaquin Valley.

Maricopa shale (*Miocene*).—Marine brown siliceous shale with diatoms, equivalent to Monterey and Salinas shale of other areas. Maximum thickness about 10,000 feet. The upper few thousand feet are softer shale, layers of soft white sandstone, and granitic boulder beds, known as the Santa Margarita phase of the Maricopa shale. The upper phase yields oil in the Sunset-Midway field.

[1] Presented before the Association at the Tulsa meeting, March 26, 1927.

Etchegoin formation (*lower Pliocene*).—Marine sands and clays with abundant sea shells. Rests unconformably on the Santa Margarita and older formations,

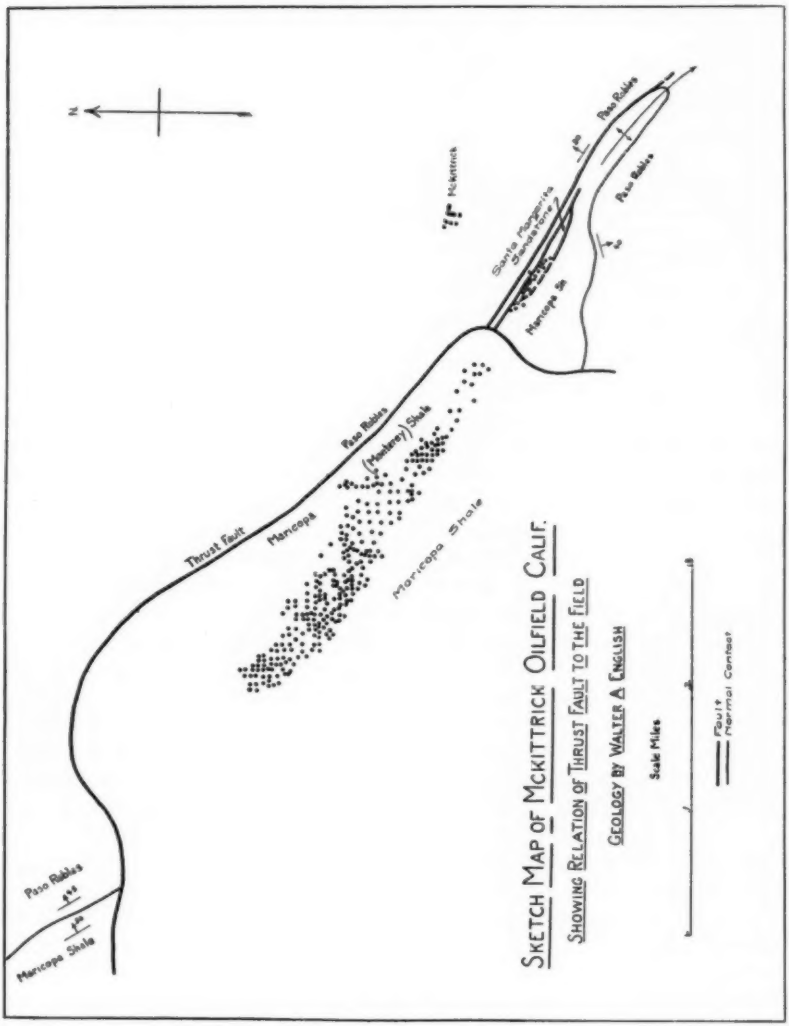

FIG. 1

though the break between it and the Santa Margarita is not always prominent. Most of the oil of the Sunset-Midway field comes from this formation.

Paso Robles formation (*upper Pliocene*).—Marine- and fresh-water clays and

sands. Markedly unconformable on the Etchegoin and all older formations. Basal beds yield considerable oil where they overlie the Etchegoin or Santa Margarita, but not elsewhere.

All formations are steeply folded and faulted, the chief period of deformation being of post-Paso Robles age.

The most prominent structural feature of the McKittrick field is an irregular overthrust fault, which obscures the significant structure with regard to oil accumulation over most of the field. The productive area is about 4 miles long and from a few hundred feet to about half a mile wide. Except at the extreme south end of the field the wells pass through the Maricopa shale, and obtain oil from the underlying Etchegoin formation. The latter is identified by sea shells which have been obtained from the drill cuttings.

The Maricopa shale on the surface of the overthrust area dips steeply and irregularly, and is much contorted, brecciated, and silicified. There are many vein tufa deposits, formed by superficial migration of water along planes of minor faulting. Irregular inliers of Paso Robles and Santa Margarita formations are folded and faulted into the Maricopa shale. Most of the lesser faults are of the steep hade type, and some of them belong to a period of faulting subsequent to that of the main thrust. Many secondary thrust faults of fairly low hade may be seen, but the main fault is not well exposed except at the north end where it bends around toward the west.

The presence of the steep hade faults is important in relation to the producing structure. The fact that the central part of the field follows a strike valley, along the sides of which vein tufa is unusually plentiful, suggests that the faults determining this valley have also had an effect on the position of the productive sands.

At the extreme south end of the field, a small productive area is left uncovered by the overthrust. Here the oil comes from nearly vertical beds of Santa Margarita sandstone, which form a faulted inlier in the Maricopa shale. Distinct oil seeps and tar sands are found along the faults which bound the inlier, and mammal bone deposits similar to those of Rancho La Brea have been found in this locality.

Farther north, the irregular outline of the productive area indicates that the structure just described does not extend any great distance northwest beneath the overthrust shale. The structural control determining the area of oil occurrence in the central and northern part of the field will probably never be determined accurately, as the only available data is that furnished by old well logs, most of which are not very satisfactory for correlation purposes.

In the writer's view, the structure, and the stratigraphic conditions beneath the thrust plane, and not the presence of the thrust fault, are the controlling features which determine the presence of the productive area. We have already seen that the production is not limited southeast by the area of overthrust shale. To the northwest the field ends where the overthrust shale extends a maximum distance northeast. If the overthrust were the determining feature we should expect the field to be at its best at the point where it ends. In some parts of the field

the productive sands are immediately beneath the thrust plane, and here the shale may serve as an impervious capping. At other places the oil is obtained several hundred feet deeper than the lowest Maricopa shale encountered in the wells.

About a mile northwest of the end of the field, and approximately in line with its trend, a normal contact of steeply dipping Maricopa shale and Paso Robles formation emerges from beneath the thrust plane. The absence of evidence of oil here is accounted for by the writer by the absence of the Santa Margarita and Etchegoin formations at this point.

The only interpretation of surface structure in this field, of which the writer is aware, other than that of an overthrust, is that of Mr. J. A. Taff, of the Southern Pacific. He believes that the overriding of younger formations by the Maricopa shale is of a superficial character, and should more properly be considered an extensive landslide rather than a thrust fault.

In most references to this field, the thrust fault is considered to be the controlling feature determining the presence of the oil field. This is in error, as the overthrust shale in only a few places forms the roof over the oil-bearing beds, and in most of the area the thrust block simply serves to obscure the significant structure. Due to the fact that the significant structure in this field will always be subject to considerable doubt, the writer would suggest that it is unwise to use this field as an example of oil occurrence under conditions of overthrust faulting.

THE EFFECT OF GRAVITATIONAL COMPACTION ON THE STRUCTURE OF SEDIMENTARY ROCKS: A DISCUSSION[1]

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ABSTRACT

Some of the conclusions in Hedberg's valuable paper on the effect of the compacting of clay rocks upon the structure of strata overlying buried hills seem to be more sweeping than the data warrant. Hedberg's average depth-porosity curve is based upon assumptions which greatly affect its accuracy. The present writer points out that the available data indicate that the void ratio of shale (the relative proportion of voids and solids) varies inversely as the depth of burial. This empirical relation is but a slight modification of a theory proposed by Sorby, it is similar to van der Waal's (gas volume) equation, and it seems to lead to acceptable geologic conclusions.

Hedberg showed that by his average curve the present writer's suggested explanation of an anticline in western Kansas was improbable. However, by the modification of Sorby's theory, this explanation appears quantitatively possible. Even granting that the two methods of computing structure are equally logical, the large discrepancy between the results demonstrates that Hedberg's method is not sufficiently accurate for use as a quantitative test. Although several of Hedberg's other conclusions seem questionable, it is desirable to emphasize the fact that his paper opens up interesting vistas upon many fields of geologic study.

Geologists interested in the structure of the Mid-Continent oil fields or of any other gently folded region are indebted to Hollis D. Hedberg[2] for his discussion of the loss of volume in argillaceous rocks due to weight of overburden. The theory that many gentle folds have been formed by gravitational compression of shale beds has been gaining supporters for years, but heretofore no one seems to have made a critical analysis, based upon laboratory experiments and existing scattered data, of the processes involved. The very excellence and timeliness of the paper make me wish to record my objections to some conclusions which seem to me unwarranted.

Among others, I have been very much interested in the theory, and have even been guilty of suggesting that it might explain the folds in certain areas. In fact it is one of these speculations of mine which Hedberg picks out as a more or less horrible example of the limits to which the theory has been pushed. As I am unable to agree with his general conclusions, I cannot accept his disproof of my application of the theory, and I shall attempt to state here the grounds for my dissent.

Hedberg points out reasons for thinking that the great loss of volume which clays undergo when buried under other rocks is due chiefly to loss of water or of pore space, rather than to chemical or mineralogic changes, and that loss of porosity by cementation in impermeable clays is relatively unimportant. He cites

[1] Received by the editor, March 11, 1927. Published by permission of the Director, U. S. Geological Survey.

[2] Hollis D. Hedberg, "The Effect of Gravitational Compaction on the Structure of Sedimentary Rocks," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926) pp. 1035–72.

data from the laboratory and field, and statements by other investigators, in support of this conclusion. If it is true that the density of clay particles remains essentially constant during compacting, and if the loss of pore space in clay is almost entirely due to increasing depth of burial, then the porosity of a rock can be used as a measure of the total volume, for by definition the porosity,

$$P = 100 \times \frac{\text{rock volume} - \text{mineral volume}}{\text{rock volume}}$$

and rock volume varies as $\frac{100}{100-P}$ or as $(1+\frac{P}{100-P})$. Therefore, if a relation between pressure (or depth) and porosity can be established by experiment, the effect of compacting upon rock volume can be calculated. It is such an experimental relation which Hedberg seeks to determine from laboratory experiments and porosity determinations of well cuttings.

The laboratory data show that porosity decreases markedly with increasing pressure, rapidly at first and then more and more slowly. Hedberg recognizes that these laboratory determinations give an unduly flat curve, that is, that the porosity falls off more slowly than it would in nature, for the following reasons: (1) There is friction between the clay and the sides of the receptacle in which it is being compressed. (2) The escape of water depends upon the permeability of the clay, and a long period of time is necessary for the porosity to become completely adjusted to a given pressure. Under geologic conditions there is plenty of time; in the laboratory there is a tendency to take the reading before the rock volume has attained an equilibrium. (3) The initial porosities of the laboratory specimens may be unduly low because of (*a*) the impossibility of restoring a laboratory specimen of a compacted clay to the condition of fine division it had when first deposited, and (*b*) the fact that the initial porosity as determined in experimental work is actually the average porosity of a column, on the lower part of which the pressure is more than zero. These possible errors in the initial porosity are somewhat offset by the flocculation and wave-action which some natural clays undergo, but the errors due to friction and rate of permeability are not similarly compensated.

Like the laboratory data, the porosities of shale cuttings from wells decrease with increasing pressure, with large decreases at shallow depths, and at greater depths smaller and smaller decreases. However, unlike the laboratory data, the well cuttings are not subject to any systematic error that makes the results always wrong in one certain direction. It is, of course, true that the original material in wells varies from bed to bed, and the effects of squeezing and crushing by the drill and of washing and crumbling during sampling materially affect the porosity of samples. Also the thickness of rocks once present in an area but now removed by erosion is unknown, and must be estimated from thicknesses at distant places. But all these sources of error are accidental and tend to vary about a true value which should be closely indicated by an average of several determinations.

From laboratory and well data and theoretical considerations, Hedberg shows that the volume of shale varies roughly in inverse proportion to the pressure exerted upon it. Probably all readers will share his wish to apply this generalization as a test to the compaction theory of structure. However, it is his transposition of the fundamental data into a form suitable for this purpose that I consider unsatisfactory. He combines the depth and porosity determinations of well and outcrop samples and smooths these average figures into a curve to be used for clay shale from all regions. In order to make this combination into one curve, two important assumptions are necessary:

1. That there is a fundamental depth-porosity curve which, other things being equal, all shale tends to follow as it is compressed. Except for the Ranson well in western Kansas, Hedberg does not state what data he used for his averages nor what he estimates as the thickness of eroded rocks. However, using all his data and making the most favorable estimates for eroded thicknesses, it is obvious that, though a series of determinations from any one well makes a fairly smooth curve, each series diverges greatly from his average curve. For example, at an estimated original depth of 2,500 feet, the shale from the Ranson well has about 25 per cent porosity, and that from the Lynn well, about 8 per cent; at this depth his curve shows a porosity of about 20 per cent.

2. That the initial porosity of 100 feet of shale is about 50 per cent. From the observational data previously cited in his paper it seems that the average initial porosity might as well have been estimated at 40, 60, or 80 per cent. The quantitative value of Hedberg's curve depends greatly upon this assumed initial porosity. From his depth-porosity curve he determines that 100 feet of mud, when buried under 3,000 feet of sediment, will be reduced to about 60 feet; from the same curve, but with an initial porosity of 75 instead of 50 per cent, the 100 feet of mud would have been reduced to 30 feet. And instead of 180 feet, which he states was the original thickness of 100 feet of shale with a porosity of 8 per cent, the original thickness would have been about 370 feet.

True, Hedberg frankly disclaims mathematical accuracy for his curve, but these cautions seem forgotten where, farther on in the paper, in making quantitative applications to specific folds, he estimates his results as accurate to within less than half their computed values, and recommends that these results be applied as a quantitative test to structural theories. As the errors from assumptions in his method may cause large errors in the results, it is manifestly desirable to eliminate, if possible, these questionable assumptions. If the compaction theory is to be tested by his studies, it should be by some method of treatment which, though taking into consideration all laboratory and field determinations, does not agglomerate dissimilar series into a single average curve, and which does not call for, or weight so heavily, an assumption of the initial porosity.

Re-examining the fundamental data, I find that all the laboratory determinations of load and porosity, when plotted on logarithmic paper, fall surprisingly close to straight lines, following the hyperbolic equation LP^n = a constant for each

sample, where L indicates the load or pressure applied, and P the observed porosity. These data fit equally well an equation, $L\left(\frac{P}{100-P}\right)^m$=a constant, wherein the relative proportion of voids and solids, called by Terzaghi[1] the void ratio, is used instead of the simple porosities. Both equations express rather accurately the observed relation between load and porosity. The second, and somewhat less simple, of the two is discussed here because, in the light of other investigations, it seems to be the more significant. Sorby[2] found that the ratio of solids to voids is a function of the pressure exerted upon argillaceous rocks, and, as shown in a following paragraph, Hedberg's well data likewise show a relation between depth and void ratio.

For Terzaghi's laboratory data, which Hedberg quotes, the values of the exponent m in the equation, $L\left(\frac{P}{100-P}\right)^m$=a constant, range from about 18 for dense and loose sand, through 9 for yellow pottery clay, to about 5 for blue marine clay and sandy delta mud. This means that the finer-grained clays lose their porosity more readily than do the coarser sands. For Hedberg's own data the exponent m is about 80 for a sandy residual clay, and 30 for an English kaolin. As the two sets of experiments were performed under different laboratory conditions, the results are not strictly comparable, but both sets of observations show the same relative behavior of fine and coarse material and give a curve of the same general hyperbolic equation. Now Hedberg recognized that in nature the porosities would fall off more readily than they do in the laboratory experiments; that is, in nature the exponent m would have lower values. For rocks of the same degree of coarseness, Terzaghi's data give lower values of the exponent m than do Hedberg's. Of the two laboratory methods, Terzaghi's approximated nature more closely, for he used a receptacle with a greater diameter[3] than did Hedberg, thereby reducing the effects of friction on the sides, and he attempted to allow for the effect of time on the escape of water from compressed clay. The laboratory data thus are in conformity with the theoretical conclusion that the value of the exponent m decreases as the conditions under which pressure is applied approach those obtaining in nature, and the inference seems warranted that for the finest-grained sediments under natural conditions this value is less than 5.

The series of porosities of shale from wells require a somewhat different treatment. The present depth is less than the original depth because of erosion, and even if the original total depth were known, it could not be treated as the equivalent of pressure, for, as density varies inversely with volume, we have just seen

[1] Charles Terzaghi, "Principles of Soil Mechanics: Determination of Permeability of Clay," *Eng. News-Record*, Vol. 95 (1925), p. 832.

[2] Henry Clifton Sorby, "On the Application of Quantitative Methods to the Study of the Structure and History of Rocks," *Quart. Jour. Geol. Soc. London*, Vol. 64 (1908), pp. 227–31.

[3] Terzaghi, *op. cit.*, "Phenomena of Cohesion of Clay," p. 743; "Elastic Behavior of Sand and Clay," p. 988.

that the density of shale increases with thickness of overburden. By the method of trial and error, it was found that the well data fit closely to a curve with the equation $(D+A)P=K$, a constant for each well, where D represents the observed depth; A, an empirical constant for each well; and P, the observed porosity. By crude analogy with the first equation based upon laboratory experiments, $LP^n=$ a constant, the sum $(D+A)$ might be taken as the original thickness of overburden before erosion, and this would mean that A represents the thickness of rocks eroded. However, with this interpretation the equation $(D+A)\,P=K$ cannot be extrapolated above the present surface without becoming absurd. That is, if A correctly represents the eroded thickness, at depths where $(D+A)$ is less than $K/100$, the computed porosity would be greater than 100 per cent, a clearly impossible case. Observed porosities of recently deposited argillaceous sediments cited by Hedberg and Terzaghi[1] range up to 98 per cent and are commonly from 70 to 90 per cent. Both from these actual observations and from theoretical considerations, the inference seems justified that as the depths decrease toward zero as a limit, porosities asymptotically approach 100 per cent as a limit. This is not an estimate of the initial porosity at some depth, but an assumption that in a mixture of clay and water the contact between the two substances is more or less gradational, and that above the highest clay particle there is 100 per cent of water, but that below this upper surface of clay the percentage of water is something less than 100 per cent.

If this inference is correct, the equation $(D+A)P=K$ can be re-written to avoid the absurdities. The change can be made by taking the term A as the sum of two other terms, $-B$, the eroded thickness, and C, a constant equal to $K/100$. This would make the equation read $(D+B+C)\,P=K=C\times 100$ or $(D+B)\,\frac{P}{100-P}=C$. That is, the product of the total original depth and the void ratio is a constant for each well.

In this revised form the equation makes use of the void ratio instead of the simple porosity, and it is but a slight modification of the theory proposed by Sorby, "father of petrography," in what were virtually his last written words,[2] that in argillaceous rocks the ratio of solids to voids varies with the depth. In his equation expressing this relation, Sorby had another term, 32 per cent, which he supposed was the original porosity of clays, but observations made since the appearance of his paper justify its omission in a re-statement of his theory now.

Furthermore, this relation between depth and void ratio is not inconsistent with the relation between load and void ratio found in laboratory experiments. From the exact mathematical relation between density and porosity, and from the empirical relation between porosity and depth, we can calculate the weight of a column of argillaceous rock. This integrates to $W=Sm\left[T-C\log\left(\frac{T+C}{C}\right)\right]$,

[1] Charles Terzaghi, *op. cit.*, "Physical Differences between Sand and Clay," p. 912.

[2] Henry Clifton Sorby, *op. cit.*

where W represents weight per unit area, Sm the density of the mineral grains, and T the total depth, or $D+B$. Stated otherwise, this means that at great depths the weight or load is nearly proportional to depth, but that at shallow depths it increases as some higher power of the depth. Hence it follows from the equation $(D+B)\frac{P}{100-P}=C$ that for argillaceous material under natural conditions, the exponent m in the equation based upon laboratory data, $L\left(\frac{P}{100-P}\right)^m=$a constant, should be somewhat more than 1 for moderate loads. This deduction accords with the conclusion, based upon consideration of the accuracy of laboratory experiments, that it should be less than 5. Therefore the two equations, $L\left(\frac{P}{100-P}\right)^m$ =a constant and $(D+B)\frac{P}{100-P}=C$, express approximately the same relation between load or depth and void ratio.

It may be of some interest to note that the empirical equation $(D+B)\frac{P}{100-P}=C$ is very similar to van der Waal's equation expressing the relation between the volume and pressure of a gas. The weight of the superposed column of rocks may be taken as the equivalent of the term in the gas law indicating "external pressure." The quantity, $C \log \frac{D+B+C}{C}$, in the integrated empirical equation, varies as log $\frac{100}{P}$; the correction for "internal pressure" in van der Waal's equation varies inversely as the square of the volume or as $\left(\frac{100-P}{100}\right)^2$, and therefore approximately as log $\frac{100}{P}$, especially for porosities between 10 and 50 per cent. The void ratio in the empirical equation varies precisely as the gas volume corrected for molecular volume. Thus the two equations correspond precisely except for one term in each, and these exceptions vary almost together throughout the common range of porosities.

Applied to Hedberg's data from the Ranson well, the equation $(D+B)\frac{P}{100-P}=C$ shows a close agreement between the observed and computed values (see also Fig. 1).

In western Kansas the Cretaceous strata lie unconformably upon Paleozoic rocks and, because of this unconformity, Cretaceous shale might be expected to have porosities indicating much less overburden than would Paleozoic shale. It is interesting to note that the outcrop samples from the Ranson well do not have porosities disproportionately higher than the deeper samples. In fact, values for the eroded thicknesses computed from the outcrop samples average about 150 feet greater than do those computed from the deeper samples. This seems to be ample justification for including the values computed from the outcrop samples in with the others in obtaining a general average. This uniformity in the porosity

gradient indicates that the thickness of post-Paleozoic rocks deposited in the area at one time equaled or exceeded the thickness of rocks eroded between Permian and Cretaceous times. This would mean that the unconformity represents less than

TABLE I

RANSON WELL, SEC. 5, T. 26 S., R. 41 W., HAMILTON COUNTY, KANSAS

Present Depth in Feet D	Original Depth (Present Depth + Eroded Depth)* $D+B=D+1{,}970$	Observed Porosity P	Computed Porosity† $=\frac{C\times 100}{D+B+C}=\frac{65{,}200}{D+1{,}970+652}$	Difference between Observed and Computed Porosity
Graneros shale outcrop = 0...	1,970	$\left\{\begin{matrix}25.16\\24.57\end{matrix}\right\}$ 24.86	24.9	0.0
3,029–40	5,005	11.62	11.5	0.1
3,945–50	5,918	$\left\{\begin{matrix}9.17\\10.98\end{matrix}\right\}$ 10.08	9.9	0.2
4,485–95	6,460	8.96	9.2	0.2
4,797–4,805	6,771	9.62	8.8	0.8
4,994–5,006	6,970	8.71	8.6	0.1
5,355–60	7,328	$\left\{\begin{matrix}7.94\\8.38\end{matrix}\right\}$ 8.16	8.2	0.0
5,437–40	7,408	8.09	8.1	0.0

* The eroded depth, 1,970, is an average of the values computed from each pair of observations by the derived equation, $B=\frac{P_2D_2(100-P_1)-P_1D_1(100-P_2)}{100(P_1-P_2)}$.

† The constant, 652, is an average of the values computed from the equation, $C=(D+1{,}970)\frac{P}{100-P}$.

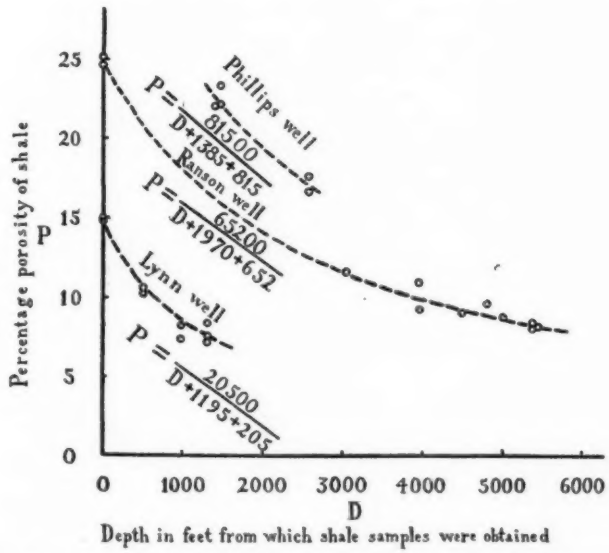

FIG. 1.—Comparison between observed and computed porosities of shale samples from three Kansas wells.

about 2,000 feet of erosion, a conclusion which seems to be in accordance with stratigraphic evidence.

It is also of some interest that the computed value of the eroded thickness, about 2,000 feet, is less than Hedberg's estimate of about 2,500 feet. However, it seems quite probable that Hedberg's figure may be too large, for it is based upon the thickness of these rocks farther west in Colorado, where, from known paleogeographic relations, greater thicknesses would be expected.

The equation agrees with the data from the other wells with about equal closeness (see Fig. 1), and the values of B and C in the Phillips well in central Kansas are 1,385 and 815, and in the Lynn well in eastern Kansas, 1,195 and 205, respectively. The thickness of the rocks that have been eroded near the Lynn well is probably between 1,000 and 2,000 feet,[1] and the computed value of about 1,200 falls within these limits. It is worth noting that the computed values of the eroded thickness decrease eastward across Kansas, a progressive change that might be expected from purely stratigraphic considerations. It is well to bear in mind, however, that the data from the Phillips well are scanty, and that the computed values are consequently not highly reliable. Judged by the data from the Ranson and Lynn wells, values of B computed from porosity determinations at but two depths have a probable error of about 20 per cent, and therefore the eroded thickness at the Phillips well should probably be considered as an amount less than 1,700 and more than 1,100 feet.

The equation also seems to fit the few available porosity determinations of recently buried sediments with the constant C equal to 50 or 100. It seems unbelievable that the porosity of clay and shale should vary so regularly with depth, and we would expect that some other relation holds, at least at very shallow depths. However, the available data of any sort are so meager and fit the simple equation so closely that there seems to be no adequate justification for assuming as a first approximation some more complex relation between the two variables.

The hyperbolic equation $(D+B)\frac{P}{100-P}=C$, therefore, gives values that agree rather closely with observations throughout the range of the data; it can be extrapolated without any very obvious absurdity; it is similar to a theory derived by Sorby from data on other argillaceous rocks, and to an equation based on the compaction of clay in the laboratory; and in the examples studied it leads to acceptable geologic conclusions. From its apparent generality it seems, therefore, that this modified form of Sorby's theory furnishes a possible method for testing the validity of the compaction theory of structure. As was stated in a preceding paragraph, rock volume, by definition, varies as 1+void ratio. Hence, if the proposed theory is correct, the volume of an argillaceous rock varies as $1+\frac{C}{D+B}$. As B and C can be computed from porosity determinations at two or more depths, it is theoretically possible to calculate the ratios between rock volumes at varying depths, and to deduce the effect of compacting upon structure without a direct

[1] R. C. Moore, personal communication.

assumption of any initial porosity and without agglomerating separate hyperbolas of different series of data into some one average curve. It seems to me that this method, which is based upon all the available evidence, has at least as much to recommend it as the one used by Hedberg.

A process whereby shale may be compacted contemporaneously with sedimentation so as to form an anticline is clearly described by Hedberg,[1] and by following his treatment step by step, but substituting the modification of Sorby's theory and its corollaries for the curve he uses, we can calculate the amount of expected closure on a bed at any depth.

In order to simplify his calculations of the amount of closure on a bed, Hedberg assumed that the average depth of the shale underlying an intermediate key bed could be taken as the total depth at any stage minus one-half the *original* thickness of the shale beds underlying the key bed. Actually, however, this average depth would be the total depth minus one-half the *compacted* thickness of these underlying beds at that stage. The error from his assumption is not great unless the porosity gradient is rather steep; but it should be noted that, even granting the accuracy of the rest of his method, this erroneous assumption always makes his calculated closure on intermediate key beds too low. However, to avoid introducing other divergences between the two methods of testing compaction, I have followed his method of determining average depth, although it makes my results closer to his than would otherwise be the case.

From his analysis of the effect of compaction upon structure, Hedberg deduces figures that he applies as a quantitative test to my tentative explanation of the origin of the Fairport-Natoma Anticline in central Kansas.[2] I concluded that this fold was probably the surface reflection of a buried fault scarp, and Bass and I estimated that in the surface rocks over the fold the structural relief is about 100 feet. It should be borne in mind that structural relief is in every case greater than closure, and that if we start with the structural relief in the surface beds and follow Hedberg's analysis of compaction, we obtain a figure that might be called the maximum topographic relief on the supposed land surface, and not the height

[1] He starts with a granite hill 100 feet high, buried by marine muds and just capped by a horizontal key bed. After another 1,000 feet of sediments had been deposited, the original 100 feet of mud surrounding the hill would be compacted to a lesser thickness and the key bed would be warped so as to show some closure, the amount of which can be calculated from the average depth, at that stage, of the strata underlying the key bed. As the lower muds were being compacted, a compensating thickness of sediment was deposited in the downwarping areas around the buried hill, thus maintaining a level sea floor so that a second key bed, laid down at the top of the 1,000 feet of later muds, would be horizontal. When 2,000 feet of muds had been deposited over the hill, the closure on the lower or first key bed would have become still greater and the intermediate or second key bed would be warped into a certain amount of closure which would be less than that on the lower bed because of the additional sediment previously deposited around the buried hill. The amount of this closure can be calculated from the average depth of the shale underlying the intermediate key bed and the thickness of the additional sediment previously deposited. Thus, with increasing depth of muds over the buried hill, successively higher beds would show successively less closure.

[2] W. W. Rubey and N. W. Bass, "The Geology of Russell County, Kansas," *State Geol. Surv. Kans. Bull. 10* (1925), pp. 66–85.

of a buried hill above the highest adjacent point, as would have been the case had we started with the amount of closure.

From his deduced figures and some necessary assumptions as to the thickness of rocks eroded from the fold, Hedberg concludes that considerably more than 1,000 feet of relief on the post-Mississippian erosion surface would be necessary to account for 100 feet of relief in the outcropping beds. He considers 1,000 feet of relief too great, and accordingly rejects my explanation. However, following Hedberg's method of analysis, including his method of determining average depth, but using the modified form of Sorby's theory with an eroded thickness of 1,400 feet (derived from Hedberg's data on the Phillips well, which lies less than 15 miles east of the fold), and with a constant of either 815 or 652 (the computed constants for the two western Kansas wells), I obtain a calculated topographic relief on the post-Mississippian surface of about 400 feet. This amount, it seems, is not much greater than might be expected from the known relief between Mississippian and Pennsylvanian rocks in other areas.

By a very different method I estimated, several years ago, the maximum topographic relief on the post-Mississippian surface in the Fairport-Natoma Anticline as about 600 feet. This method is based on the observation that in at least a few Mid-Continent fields there is a surprising tendency for the proportion of thickening in any one well to be the same, regardless of what interval is used. That is, if on the crest of a certain fold the interval between the two highest recognizable beds is 100 feet and this same interval in a well on the flanks is 110 feet, then an interval of 1,000 feet on the crest will correspond with an interval of 1,100 feet in the lower well, and a 2,000-foot interval with one of 2,200 feet, and so on. The departures from this puzzling little rule of thumb are of the sort that might be explained by miscorrelations or by regional thickening, though it seems there is generally a slight increase with depth even in the percentage of thickening. I have no satisfactory explanation for this regularity of thickening "off-structure," but, in areas where it could be tested and where shallow wells have been drilled, I have used it as a basis for estimating the thickness and depth of deeper strata. It is as such a basis for estimates that I venture to offer it to others for whatever it may be worth. It was by this method that I calculated the figure of 600 feet for the probable post-Mississippian relief on the Fairport-Natoma Anticline from the few wells that had been drilled upon it at that time.

Although the 400 feet of post-Mississippian relief on the anticline indicated by Sorby's theory seems not unreasonable, by no means do I consider this calculation a proof that my suggested explanation of the anticline is correct. Compaction may cause folds by some method other than that on which the calculation is based. For example, it would be useless to spread a bedroll on rough ground if the irregularities on the upper surface of the mattress were as great as those on the ground. The same thickness of bedding is deposited over the entire surface, but distortion of the mattress smooths out the irregularities—more or less. The analogy is not perfect, but it illustrates another possible cause of increase of folding with depth over buried hills which I think Hedberg dismissed too readily. Clay landslides down

the slope of a buried hill during or after sedimentation would also account for greater thicknesses of shale "off-structure." Sedimentation and compaction *pari passu* may be, as Hedberg assumes, the principal factor; but any stretching and squeezing of strata comparable to the distortion of the bedroll mattress or any slipping of clay beds would vitiate the quantitative accuracy of calculations of the amount of closure on strata over a buried hill based on his assumption. Furthermore, folds that resemble those formed by compaction may be due to some other process. Many Mid-Continent folds have characteristics which show that compacting was an unimportant factor in their formation. The chief of these characteristics seem to me to be (*a*) a marked inclination of axial planes, (*b*) increasing dip with depth even in the deeper-lying, less compactible limestone series, and (*c*) the definite evidence of post-Pennsylvanian movement, such as the *en échelon* faults of northeastern Oklahoma. My suggested explanation of the Fairport-Natoma Anticline remains a hypothesis unless more complete drilling demonstrates the absence of such characteristics.

One of the most widely favored explanations of the increase of folding with depth so common in the Mid-Continent region is that there have been repeated vertical movements contemporaneous with deposition, and it is by a modification of this theory that Hedberg proposes to explain the Fairport-Natoma Anticline. I considered this theory in the Russell County bulletin, but dismissed it as unsatisfactory. My chief objections to it were: (1) that the extremely uniform increase of dip downward on this fold calls for too uniform and long-continued an uplift, and (2) that repeated uplift along a fault would form a sharp monocline, not an anticline.

Hedberg points out that increase of folding with depth does not necessarily imply compacting; but I cannot agree with him that parallel or concentric folding may be an adequate explanation of this characteristic. At one time I considered this possible interpretation rather favorably,[1] but I have since concluded, chiefly from attempts to apply it quantitatively, but also from considerations of the probable type of folding in shale,[2] that it is very probably not a factor of recognizable dimensions in the post-Mississippian rocks of the Mid-Continent oil field.

His four possible explanations of inclined axial planes also seem to me unsatisfactory: His first, that inclination might be caused by regional tilting, clearly does not apply to the Mid-Continent oil field, for with the regional dips and drilling depths common there it would cause a horizontal difference of less than 50 feet (considerably less than could be detected by normal well spacing), whereas in some Mid-Continent fields this difference is 1,000 to 2,500 feet or even more.[3] His second and fourth suggestions are based on the assumption of parallel or concentric

[1] W. W. Rubey, "Progress Report on a Subsurface Study of the Pershing Oil and Gas Field, Oklahoma," *U. S. Geol. Survey Bull. 751* (1923), pp. 52–53.

[2] W. W. Rubey, "Determination and Use of Thicknesses of Incompetent Beds in Oil Field Mapping and General Structural Studies," *Econ. Geol.*, Vol. 21 (1926), pp. 333–51.

[3] Carl H. Beal, "Geologic Structure in the Cushing Oil and Gas Field," *U. S. Geol. Survey Bull. 658* (1917), p. 27; P. V. Roundy, K. C. Heald, and G. B. Richardson, "Structure and Oil and Gas Resources of the Osage Reservation, Oklahoma," *U. S. Geol. Survey Bull. 686* (1922),

folds. As this assumption seems to me unwarranted where shale makes up a large part of the stratigraphic section, I do not think the two causes he suggests are important factors in those parts of the Mid-Continent region in which I have worked. In fact, it seems to me that a more reasonable case can be made for the assumption that in plastic beds the axial plane inclines toward the steeper side of a fold. His other explanation—buried sand lenses—may possibly be an adequate one if it is found that the inclination is commonly a random, unsystematic feature. My own experience has led me to think this inclination is systematic in some fields, and if this is usual, it would be extremely difficult to explain why the sand lenses have such a peculiarly regular distribution. This inclination is certainly difficult to account for under any hypothesis, and, though I do not think Heald's suggestion in the Pershing bulletin altogether satisfactory, his explanation that it is due to horizontal movement seems to fit the facts better than any alternative hypothesis I know.

Finally, I cannot share Hedberg's optimistic belief that the porosity of shale beds may be (1) a valuable check on the plausibility of ascribing folding to the lateral transmission of stresses and (2) a rather sensitive index of the metamorphism due to lateral pressure which a region has undergone. It seems to me that the soft, argillaceous rocks would not be called upon to transmit horizontal stresses, but that these weak strata would normally ride upon the deeper-lying, less compactible rocks during horizontal movement. If this concept is correct, the small amount of the compaction which the deeper-lying rocks could undergo would set the limit to the compaction of the overlying argillaceous strata. Where intensely folded, tilted, and faulted, the shallow soft rocks would, of course, undergo considerable compacting from horizontal stresses, but in areas of relatively flat structure, such as most oil fields, I do not think horizontal stresses could have a perceptible effect on porosities.

However, the close relation between shale porosities and pressure brought out in Hedberg's paper may be of geologic significance in other ways. If Sorby's theory should be verified by additional studies, it will furnish a basis for estimating the thickness of rocks that have been eroded from an area both above its present surface and along buried planes of unconformity. It may also be used to predict the approximate amount of buried structure in a region, and the porosity of shale beds thought to be a source of oil. It may tell the sedimentary petrographer the approximate thickness of annual layers to be expected in any argillaceous rock. The geophysicist may have use for the relation between density and depth postulated in the theory in calculating the elastic expansion of rocks following erosion and in interpreting gravity anomalies. In short, the proposed modification of Sorby's theory is very interesting, if true.

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p. 407; W. W. Rubey, "Progress Report on a Subsurface Study of the Pershing Oil and Gas Field, Osage County, Oklahoma," *U. S. Geol. Survey Bull. 751-b* (1923), pp. 42–43; John W. Merritt and O. G. McDonald, "Oil and Gas in Creek County, Oklahoma," *Okla. Geol. Survey Bull. 40-c* (1926), p. 16.

GEOLOGICAL NOTES

LOST LAKE SALT DOME, TEXAS

A new salt dome was discovered January 22, 1927, by the Pure Oil Company, near Lost Lake, about two miles northwest of Wallisville, Chambers County, Texas. This is another seismograph dome. Credit for outlining this prospect goes to George M. Bevier, division geologist for the Pure Oil Company at Houston, Texas. The discovery was made by Geophone troup No. 3 of the Geophysical Research Corporation in charge of Dr. B. B. Weatherby.

Lost Lake is in a low marshy area close to Trinity River. A gas seepage in Lost River has been generally known for some years. During 1925 the Roxana Petroleum Corporation drilled a test to a depth of 3,720 feet close to the dome. This location is reported to have been made on evidence obtained by torsion-balance work.

Since the discovery other seismograph outfits have checked the existence of this dome.

T. WASSON

CHICAGO, ILLINOIS
April, 1927

FOSSIL FOOTPRINTS NEAR ABILENE, TEXAS

In 1908 Dr. S. W. Williston published the following note regarding fossil footprints found near Abilene, Texas. This article, reproduced here in part, was illustrated with photographs of several of the footprints.[1]

Recently, Miss Augusta Hasslock,[2] of Abilene, Texas, High School, has had the kindness to send me a number of thin red shales showing abundant markings of raindrops, worm, or other tracks, and footprints which must have been made by some salamander-like creatures of small size. The horizon is assumed to be the Permian. The prints occur in pairs, one with clear evidence of five, and the other with but four, toes, from which the conclusion is justified that the creatures were tetradactyl in front, pentadactyl behind, as were the Branchiosauria and as are the Urodela of today. Whether or not they were real salamanders which made the prints, or Branchiosaurs, cannot be determined, but I am inclined to believe, in the light of the evidence presented by Lysorophus, that the origin of some or all of these prints is due to real salamanders of modern type.

Some five years ago Mr. W. E. Wrather first showed me the locality where these fossil footprints were obtained, at which time we collected a number of specimens. On January 10, 1927, at the time of the San Saba–San Angelo field conference, I visited the locality with Mr. Joseph M. Perkins, of Eastland, Texas.

[1] S. W. Williston, "Salamander-like Footprints from the Texas Red Beds," *Biological Bulletin*, Vol. 15, No. 1 (June, 1908), pp. 237–39.

[2] Miss Hasslock, to whom Dr. Williston refers, is now Mrs. J. F. Kemp, wife of Superintendent Kemp of the city schools at Seymore, Texas.

Under date of March 14, 1927, Mrs. Kemp kindly wrote me as follows regarding the footprints.

I discovered the footprints to which you refer in December, 1907, while teaching in Abilene. I sent samples of them to Dr. Williston, under whom I had had work the previous summer. He seemed much interested in them and intended to visit the locality the next fall, but was prevented. He published a photograph and a brief description of them.

The field work I did around Abilene I used as the basis for my Master's dissertation in Geology at Chicago. I quote a brief description, with some modifications to ensure clearness.

"Castle Peak, an outlier of the Callahan Divide, lies ten miles due south of Merkel, Texas. Its crest and middle slopes are Comanchean, but its lower slopes are Permian (Clear Fork). Near the head of an eastward-draining gulley, on the north slope of Castle Peak, was found an unusually smoothly laminated, calcareous shale. Its colors were red and green, distributed in circles and splotches, all with very clear-cut, regular boundaries. This two-foot layer contains abundant rain-drop impressions, footprints, and invertebrate trails, and frequent suncracks and ripple-marks; also what may be plant remains; but these are too fragmentary for identification."

The footprints were of three sizes. The two smaller kinds were about one-fourth and three-fourths inches long. A few similar footprints were found several miles northeast of Cedar Gap (south of Abilene, Texas), associated with invertebrate trails, in a thinly laminated, friable sandstone, which preserved them imperfectly and crumbled readily. The largest prints from Castle Peak were about an inch long, and *apparently* two-toed.

Dr. Williston insisted that fossil bones would be found, but I never found any until after his death. These were in calcareous concretions from the brick yard at Abilene, where they are associated with *Gigantopteris*. These specimens are in the collection of the Bureau of Economic Geology at Austin.

Castle Peak, the Cretaceous outlier, is in full view of the Texas & Pacific Railroad and of the highway near Merkel. The fossils occur on the north slope of Castle Peak, about a quarter of a mile north of the peak itself. According to W. A. Riney, engineer of Abilene, the legal description of the land is Sec. 4, Block 9, S.P. Ry. Co. The land is now owned by the G. A. Lilly estate.

A pasture road leads east from the Lilly ranchhouse through the mesquite brush, half a mile or more, ending about 200 yards southwest of the ledge in which the fossils occur.

The formation is upper Clear Fork, corresponding roughly to the Hennessey of Oklahoma. Blowout Mountain, which was Wrather's type locality for the sandstone now known as the San Angelo sandstone, the equivalent of the Duncan sandstone of Oklahoma, is a conspicuous hill, in plain view a few miles to the west.

The footprints occur in a ledge of rather platy shale outcropping along the sides of a gully which heads just north of Castle Peak and flows east. The best specimens were found by splitting a rather hard member, 2–6 inches thick near the top of the main ledge. A half-hour's search will yield scores of very good prints.

CHARLES N. GOULD

NORMAN, OKLAHOMA
April 13, 1927

DISCOVERY OF THE YATES POOL, PECOS COUNTY, TEXAS

A newly discovered pool on the Yates Ranch in northeastern Pecos County is, in many respects, one of the most remarkable shallow fields ever opened in Texas.

The field was opened November 1, 1926, by a joint test drilled by the Transcontinental Oil Company and the Mid-Kansas Oil and Gas Company. This well was located on a vacancy strip and 2,900 feet west of the southwest corner of Sec. 60, Block 1, International & Great Northern Railway Company Survey. The top of the producing horizon was found at 995 feet.

Development of the field has been greatly retarded by lack of pipe-line facilities, and only four wells have been drilled to the pay horizon. These four wells, although only partly drilled in, have had an initial production of more than 11,000 barrels. All of these wells have sufficient gas to flow naturally. The oil has a corrected gravity of 30.9 degrees.

The initial test was located on a well-defined dome mapped on the Comanchean-Cretaceous limestones. The subsurface data available at the present time indicate that this dome is the reflection of a much more pronounced dome in the Permian formations below the Cretaceous. The production is obtained from a soft sandy phase in the Permian limestones.

Kurt de Cousser, working under the immediate field direction of Ray V. Hennen and A. M. Hagan of the geological force of the Transcontinental Oil Company, is accredited with the discovery of this dome in 1923, and Mr. Hennen, who is chief geologist for the Transcontinental Oil Company, was instrumental in securing a large block of leases for his company on the dome.

Since that time the Mid-Kansas Oil and Gas Company has acquired a one-half interest in these leases, and a very large part of the productive acreage will be developed jointly by these two companies.

R. J. METCALF

NOTE ON RANGER SAND, EASTLAND COUNTY, TEXAS

A core of the Ranger (McCleskey) sand was recently taken out of the Texas Pacific Coal and Oil Company No. 33 Norwood, in the old Ranger field, Eastland County, Texas.

This core removed all doubts as to this sand being of sedimentary origin. Small chunks of limestone, flint pebbles, and fossil vegetal remains were noticed in the core.

DAVID DONOGHUE

FORT WORTH, TEXAS
May 2, 1927

DISCUSSION

THE PRESENT STATUS OF THE CARBON-RATIO THEORY

The article by George E. Dorsey appearing in the May number of this *Bulletin* on the carbon-ratio theory is evidence that a few geologists, at least, are beginning to question some phases of this theory. Although I share Mr. Dorsey's doubt that there is a causal relationship between the geodynamic alteration of the sediments and the occurrence of oil and gas, I do not believe that one can hope to overthrow this generalization merely by citing some of the difficulties in its application, without questioning its theoretical assumptions or the criteria upon which it is based.[1] Because of the complexity of geological processes, one expects that a geological theory will encounter difficulties in its application. At any rate, the difficulties cited by Mr. Dorsey in the application of the theory in question could undoubtedly be disposed of by any of its enthusiastic supporters. Mr. Dorsey further weakens his case, it seems to me, by including, in his attack on the tenet that the occurrence of oil and gas depends upon the stages reached in the alteration of the sediments, a criticism of the generalization that the various grades of oil are the product of the forces that produced this alteration. This tenet appears sound theoretically, and is supported by a great mass of empirical data.

His suggestion that Tarr's hypothesis, which ascribes the occurrence of gas and the various grades of oil to differences in the source materials and conditions of deposition, offers a way out of the difficulties which beset the carbon-ratio theory will probably not be favorably received. It appears to me no more satisfactory than the parallel hypothesis, formerly held by some European geologists, which attributed the different ranks of coal to the differences in the original constituent material and the varying conditions under which it accumulated. Practically everyone admits that these factors play some part in determining the character of both coals and oils, but there are innumerable objections that can be raised to the suggestion that they play more than a minor rôle in the production of coals and oils of different ranks and grades.

The suggestion that the occurrence of gas along the southeastern margin of the Oklahoma and Appalachian oil fields and the non-occurrence of either oil or gas farther southeastward is due to the change from marine to non-marine sediments has little to substantiate it in the Appalachian oil field. Here the transition from non-marine to marine beds is scarcely perceptible, the oil and gas occurring where the beds are more non-marine than marine. If a boundary were to be drawn between the two classes of sediments it would be nearer the western margin than the eastern margin of the field.

FRANK REEVES

U. S. GEOLOGICAL SURVEY
WASHINGTON, D.C.

[1] In a paper now in preparation, I am pointing out that if the widely recognized fact, enunciated by Hilt in 1873, that there is a marked downward increase in the carbonization of coals, be taken into account in plotting isocarb maps, much of the evidence upon which the generalization is based appears inconclusive and that its agreement with other observational data is not wholly satisfactory.

OIL AND GAS PROSPECTS OF AUSTRALIA

In the January, 1927, number of the *Bulletin*, I note with considerable interest and pleasure a "Review of the Oil and Gas Prospects of Australia," by F. G. Clapp. It is rather refreshing to see that Mr. Clapp does not cut us off entirely from all possibilities for oil or gas, as our own press would have had us believe during his visit to this country, for we became quite familiar with big headlines such as: "No Oil in Australia," "Search for Oil Useless," etc., purporting to be based on Mr. Clapp's opinion. This no doubt was quite correct for certain specified areas on our continent, but our public was encouraged to think that it was a general condemnation.

The very slight attention that is so often given to our Tertiaries is based, in my opinion, on a number of misconceptions, and a most decided lack of knowledge of many facts concerning this very important series of our rocks. On a continent like ours it is easy to see that thin cappings of Tertiary rocks in many places might give the impression that these rocks are only of insignificant thickness and therefore negligible; but the truth of the matter is that in the big deep basins where our older Tertiary rocks have mainly accumulated we do not yet know the thickness of the series. The Portland bore in Western Victoria showed 2,270 feet still in Tertiary sediments, and several others almost as deep have also given an incomplete result in this respect. This thickness is only for a part of the marine series, and does not include the basalts which in one bored locality amounted to no less than 1,300 feet (unfinished); nor does it include the Brown Coal series.

Mountain-building appears to be assumed by some as a necessary condition for the formation of commercial oil pools in rocks of Tertiary age. Surely this cannot be upheld for all Tertiary fields. Many of our Tertiaries are practically horizontal, but in some cases, as at Torquay near Geelong, there is a very definite and regular dome structure, and close to this district faulting and folding can be seen and studied in the same series.

In the Glenelg district near Nelson the older Tertiary limestone series is about 500 feet in thickness; it is extremely porous, carries much water, and shows several surface sags frequently mistaken for structure. To determine structure in the lower members of this series, systematic boring will be necessary. Some doubt has been cast on the oil seepage on Glenelg River. I have seen this seepage and hold the opinion that it is reliable. It has been known to the local people more than thirty years.

When a small amount of crude oil is discovered it is not the usual practice to ignore and discard it; yet that is the advice given here.

There is a truly wonderful wealth of organic remains, both animal and plant, in our Tertiary series, so that there is a plentiful supply of material to satisfy the adherents to either view on the origin of oil.

In Victoria there is also an extensive and interesting Jurassic, which is a coal-bearing series, though regarded as a poor one. This is well worthy of further examination, and it may yet prove to be of high commercial value. One area of about 1,000 square miles has been bored thirteen times for coal. No workable coal—no good!

We are suffering in this country from two régimes: one based on broad generalizations with numerous assumptions which may not be correct, and the other on narrow views and ignorance; there is no doubt still room for much more work, for the collecting of facts and definite evidence on which to build our future developments.

G. B. PRICHARD

"TALAVERA"
KOOYONG KOOT ROAD, HAWTHORN
MELBOURNE, AUSTRALIA
March 3, 1927

ORIGIN OF FOLDING IN OKLAHOMA

A geological note appeared in this *Bulletin*, Vol. 11, No. 2, page 199, in which it was stated that R. W. Clark has contributed to the National Research Council a report on the origin of folding in Oklahoma. Clark states that

> the oil-bearing structures of Okmulgee County are not deformational structures, but are due to sedimentation; the topography of the pre-Wilcox was rather rugged; clastic sediments laid down on this floor slid downhill filling the valleys. This accounts for greater shale intervals on the flanks and off structure areas. The filling-up process continued until the angle of repose put a stop to it, whereupon sedimentation continued in a normal manner. The greater thickness of shale on the flanks and in the valleys caused greater compression there due to overload, thus accounting for the slighter dips in the higher formations.

The views of Clark are not supported by our field observations or our experimental data. The surface on which the earlier Paleozoic rocks were deposited was not rugged. Powers[1] states that the surface of the pre-Cambrian was "a peneplain of low relief, with small rounded hills, a few small sharp monadnocks, and some major low ridges of crystalline rocks."

A peneplain of low relief could hardly have furnished enough buried hills to account for all of our Wilcox structures and could not account for their rather closely folded attitude.

The sediments of the Mid-Continent area were deposited on peneplained surfaces or on conformable underlying beds. Therefore the surfaces on which sediments were deposited were rarely inclined more than one degree.

Twenhofel[2] quotes Walther as saying that sediments may be deposited in orderly sequence on surfaces inclined as much as 30 degrees. He also quotes Mather, who has described initial inclination of 7 degrees in limestone near Kingston, Ontario. The sediments of the Mississippi delta front have an average initial inclination of one degree. It is, therefore, difficult to conceive of the Okmulgee County sediments sliding downhill during deposition, as postulated by Clark.

There are several unconformities in the Oklahoma section, and thinning of beds on the flanks and crests of anticlines may well be due to uplift and erosion or to progressive or recurrent folding during deposition. Recurrent uplifts in this region have been noted by Powers[3] and many others. The slighter dips in the higher beds are attributed by Bloesch[4] to progressive or recurrent folding during deposition. Bloesch suggested that anticlines might even disappear upward in thick stratigraphic sections. Powers[5] also notes that "the reflected folds increase in steepness downward through the Pennsylvanian, and *especially beneath each underlying unconformity*."

The thinning of beds is not confined to the shales. Where the Boone limestone is overlapped by Pennsylvanian beds, it is commonly thinner over anticlines, due to erosion, and may be entirely eroded.

The folding in the Mid-Continent region shows considerable evidence of diastrophism. Careful detailed mapping of folds in areas of good control shows that there are

[1] Sidney Powers, "Structural Geology of the Mid-Continent Region: A Field for Research," *Bull. Geol. Soc. Amer.*, Vol. 36 (1925), p. 382.

[2] W. H. Twenhofel, *Treatise on Sedimentation* (1926), p. 433.

[3] *Op. cit.*, p. 383.

[4] Ed Bloesch, "Unconformities in Oklahoma and Their Importance in Petroleum Geology," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 3 (1919), pp. 263–85.

[5] *Op. cit.*, p. 381.

major and minor folds having the characteristic relations described by Van Hise[1] and which can only be caused by dynamic deformation.

The joint systems of the Mid-Continent region are clearly the result of regional deformation. They have a definite relationship not only to the regional structure but also to the local structure. This relationship of joints to structure has been observed by several geologists in Oklahoma and north-central Texas. Some geologists deny this relationship, but on questioning are obliged to admit that they have not actually mapped joints to determine the existence or non-existence of a relationship of joints to structure.

The lines of *en échelon* normal faults in Oklahoma could have been caused only by diastrophic movements. Powers[2] attributes these lines of faulting to "shearing stresses originating in the post-Pennsylvanian Ozark upwarp and acting against the major buried ridges which formed resistant buttresses."

The relationship of major and minor folds and the relationship of joint systems to structure are very definite proof of the dynamic origin of these structures.

The stresses which caused these structures were evidently transmitted through the basement rocks. Powers[3] suggested that "uniform compression of a large segment of the basement rocks, taking place at considerable depth below the Paleozoic crust, would accentuate buried hills, and this hypothesis is offered as the best explanation for their periodic rejuvenation."

The earlier geologists who examined this area were limited to surface observations and reported that the folds were of greater intensity nearer the mountains and of less intensity at greater distances. Powers[4] notes that studies of subsurface conditions, which were made possible by subsequent drilling, have shown that beds of the same age have suffered much the same degree of folding throughout the region.

The experiments of Bailey Willis[5] show that stresses transmitted through the beds deformed will cause relatively intense folding near the origin of the stresses and decreasing intensity of folding with distance from the origin. The experiments of Mead[6] show that stresses transmitted through the underlying material will cause folding in the overlying material which has approximately the same degree of intensity throughout the area affected.

The subsurface data noted by Powers, and the experiments of Mead, suggest very strongly that the stresses causing the folds in the Mid-Continent area were transmitted through the basement rocks.

No direct evidence has been advanced to prove that differential compaction over buried hills has ever caused structures like those of the Mid-Continent area, or that differential compaction might cause them. There is, on the other hand, very definite evidence that these structures are the result of diastrophism.

LYNDON L. FOLEY

TULSA, OKLAHOMA
May 2, 1927

[1] C. R. Van Hise, "Principles of North American Pre-Cambrian Geology," *U. S. Geol. Survey*, sixteenth annual report (1896), pp. 603–32.

[2] *Op. cit.*, p. 385. [3] *Op. cit.*, p. 385. [4] *Op. cit.*, p. 384.

[5] Bailey Willis, "Mechanics of Appalachian Structure," *U. S. Geol. Survey*, thirteenth annual report, Part 2, 1893.

[6] W. J. Mead, "Notes on the Mechanics of Geologic Structure," *Jour. of Geol.*, Vol. 28 (1920), p. 505.

REVIEWS AND NEW PUBLICATIONS

A Graphic Table Combining Logarithms and Anti-Logarithms. By Adrien Lacroix and Charles L. Ragot. New York: Macmillan Co. 7×10 in. Pp. 40. $1.40.

For those using logarithms, either occasionally or frequently, this book will have a great appeal. Five-place numbers or logarithms may be read directly in terms of one another without the troublesome process of interpolation. Actual tests show greatly increased speed and accuracy in the manipulation of logarithms by the use of these graphic tables.

Arthur Knapp

RECENT PUBLICATIONS

GENERAL

"Manual of Testing Methods for Oil Shale and Shale Oil," by L. C. Karrick. *Bulletin 249, U. S. Bureau of Mines,* Washington, D.C., 1926. 70 pp.; 24 figs. Price, $0.20.

"Safeguarding Workmen at Oil Derricks," by H. C. Miller. *Bulletin 272, U. S. Bureau of Mines,* 1927.

ALABAMA

"Geology of Alabama." *Special Report 14, Geological Survey of Alabama.* University, Alabama. The price of this report, erroneously quoted in a previous number, is $1.65, postpaid, including map.

MONTANA

"Geology of the Cat Creek and Devil's Basin Oil Fields and Adjacent Areas in Montana," by Frank Reeves. *Bulletin 786-B, U. S. Geological Survey,* Washington, D.C., 1927. 59 pp.; 3 pl.; 6 figs. Price, $0.30 (Superintendent of Documents).

TEXAS

"Foraminifera of the Midway Formation in Texas," by Helen Jeanne Plummer. *Bulletin 2644, Bur. of Econ. Geol., Univ. of Texas,* Austin, 1926. 206 pp.;15 pl.; 13 figs.

"The Gueydan, a New Middle Tertiary Formation from the Southwestern Coastal Plain of Texas," by Thomas L. Bailey. *Bulletin 2645, Bur. of Econ. Geol., Univ. of Texas,* Austin, 1926. With map.

FOREIGN

"Foreign Trade Notes No. 138, Petroleum," by Joseph S. McGrath. *Bur. of Foreign and Domestic Commerce, Dept. of Commerce,* Washington, D.C., April 23, 1927. Excerpts as follows:

Great Britain: . . . . Crude oil was discovered last December on St. Kennox farm in Pembrokeshire, Wales. Part of the farm is a marsh, where oil was first observed floating on the surface. Tests are reported to indicate a high quality of crude oil and it seems probable that the bed extends beyond the limits of the farm, though it has not been located outside so far. The bed of the farm is composed of oil-bearing shale, which has also been analyzed with reported satisfactory results. . . . . (Consul John J. C. Watson, Swansea, March 23).

Brazil: It is reported that petroleum has been accidentally encountered at a depth of 11 meters, near Rio de Janeiro (cable from Commercial Attaché Carlton Jackson, Rio de Janeiro, April 16).

Argentina: . . . . According to the Buenos Aires press, two wells just brought in the Plaza Huincul field represent the first production obtained by one of the American companies operating there. It is said that at depths of 500 and 560 meters, respectively, horizontal petroleum deposits were tapped, producing oil of high gasoline content. One is already producing 80,000 liters per 24 hours, and its production is expected to increase (Assistant Commercial Attaché H. Bentley MacKenzie, Buenos Aires, March 4).

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following applicants for membership in the Association. This does not constitute an election, but places the names before the membership at large. In case any member has information bearing on the qualifications of these applicants, please send it promptly to J. P. D. Hull, Business Manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each applicant.)

FOR ACTIVE MEMBERSHIP

Rufus Mather Bagg, Appleton, Wis.
J. B. Umpleby, Irving Perrine, D. W. Ohern

Hally L. Berry, Maracaibo, Venezuela.
E. G. Sinclair, R. L. Marston, R. S. McFarland

Garrett L. Bolyard, Cisco, Tex.
D. R. Snow, Robert H. Wood, T. K. Harnsberger

Carlton M. Carson, Tampico, Mexico.
S. A. Grogan, L. C. Keeley, P. H. Bohart

William Peter Haseman, Oklahoma City, Okla.
Stuart K. Clark, John Cullen, M. G. Gulley

Alva Vance Jones, Wichita Falls, Tex.
L. E. Trout, J. V. Howell, Charles E. Decker

Hubert F. Sackett, Tulsa, Okla.
Harry F. Wright, A. L. Beekly, Sidney Powers

William James Sherry, Tulsa, Okla.
W. J. Allen, W. C. Adams, Edward Bloesch

FOR ASSOCIATE MEMBERSHIP

Lyman P. Anderson, Ardmore, Okla.
Charles E. Decker, A. C. Reeds, Leonard W. Orynski

Millard B. Arick, Austin, Tex.
Fred M. Bullard, Hal P. Bybee, F. W. Simonds

Charles Brewer, Jr., Pittsburgh, Pa.
Roswell H. Johnson, L. G. Huntley, R. E. Somers

James Blaine Christner, Weslaco, Tex.
Fred M. Bullard, Hal P. Bybee, F. W. Simonds

Lee H. Cornell, Wichita, Kan.
Charles E. Straub, Walter W. Larsh, Geo. A. Forrester

William D. Cortright, Los Angeles, Calif.
M. G. Edwards, George R. Elliott, Frank A. Morgan, Jr.

Ira William Fox, Greensburg, Pa.
Roswell H. Johnson, L. G. Huntley, R. E. Somers

Jesse Allen Gray, Pittsburgh, Pa.
Roswell H. Johnson, L. G. Huntley, R. E. Somers
Harry Hardington Arnold, Jr., Clarion, Pa.
Roswell H. Johnson, L. G. Huntley, R. E. Somers
Roy Lebkicher, San Francisco, Calif.
G. C. Gester, E. G. Gaylord, F. A. Davies
Clarence E. Manion, Fort Collins, Colo.
James M. Douglas, C. Max Bauer, George L. Klingaman
William Blair McCarter, Austin, Tex.
Fred M. Bullard, Hal P. Bybee, F. W. Simonds
Ray R. Moody, Wichita, Kan.
Anthony Folger, Roy H. Hall, J. K. Knox
Doska W. E. Monical, Long Beach, Calif.
Guy E. Miller, Donald D. Hughes, V. C. Perini, Jr.
Allen G. Oliphant, Tulsa, Okla.
L. G. Welsh, M. M. Valerius, A. L. Beekly
Kenneth Dale Owen, Laredo, Tex.
Wallace E. Pratt, Eugene Holman, Dave P. Carlton
Robert Leo Parker, Tulsa, Okla.
Thomas W. Leach, William C. Adams, C. A. Warner
Wilbur D'Arcy Rankin, Los Angeles, Calif.
Donald D. Hughes, R. M. Barnes, R. D. Reed
John Robert Schwabrow, Pittsburgh, Pa.
Roswell H. Johnson, L. G. Huntley, R. E. Somers
Virgil Harold Welch, Tulsa, Okla.
L. B. Snider, Sidney Powers, Dollie Radler
E. D. Williams, Austin, Tex.
Fred M. Bullard, Hal P. Bybee, F. W. Simonds

FOR TRANSFER

Howell Smith Clark, Abilene, Tex.
Wesley G. Gish, D. H. Radcliffe, A. W. Duston
George Vincent Dunn, Tulsa, Okla.
Raymond M. Carr, Wesley G. Gish, Max W. Ball
Rowland W. Laughlin, Holdenville, Okla.
Lucian Walker, A. L. Beekly, Frank A. Herald

REPORT OF PROGRESS OF RESEARCH COMMITTEES

RESEARCH COMMITTEE OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

The Research Committee of the American Association of Petroleum Geologists was authorized by the Executive Committee in March, 1923. The committee was composed of W. E. Wrather, chairman; Max W. Ball, Carl H. Beal, E. L. DeGolyer, James H. Gardner, G. C. Gester, Wallace E. Pratt, W. van der Gracht, and Chester W. Washburne. The personnel of the committee remains unchanged.

A published report of progress was submitted at the Wichita meeting in 1925 which adequately set forth the policy to be pursued in the furtherance of research. At that time

an effort was made to raise a preliminary fund among geologists to be expended on research problems. It was thought that this fund raised among geologists would get a limited amount of work under way and would serve as an earnest of good faith, enabling the committee with better grace to solicit more substantial financial backing from the industry.

As a result of this effort to raise funds among members of the Association, twenty-one individuals subscribed $4,810, to be paid direct to the committee for the furtherance of such work as it might see fit to undertake. In addition, two individuals subscribed $3,700 for the prosecution of specific projects, the funds to be paid to, and administered by, the National Research Council. To date $3,390 has been collected by the committee, and, under the provision which permitted larger subscriptions to be spread over three years, a balance of $1,420 is still outstanding, though it is presumably available when needed.

The sum of $2,750 has been expended upon the following projects: (1) microthermal studies relating to the origin of oil, conducted by David White, $2,500; and (2) a study of the reduction of sulphates in oil-field waters through the agency of sulphate-reducing bacteria, conducted by E. S. Bastin, $250. Results of these investigations have appeared in the *Bulletin*. The former research has not yet been completed, but has been adequately funded from another source. The Committee has pledged, out of the $640 cash on hand, a sum not to exceed $300 for the purchase of experimental apparatus to test the permeability of sands by oil and water, the work to be done at Cornell University under the direction of C. M. Nevin.

CENTRAL PETROLEUM COMMITTEE OF THE AMERICAN PETROLEUM INSTITUTE

Following the Wichita meeting, the committee attacked the problem of adequately funding a more comprehensive program of research. An outline of various geological studies relating to oil was formulated, and this, with a similar outline prepared by the chemists and physicists, was submitted to John D. Rockefeller, who, on November 15, 1925, donated the sum of $250,000 for the furtherance of research in these sciences. On January 12, 1926, the Universal Oil Products Company of Chicago donated a similar sum. Each donor placed the administration of the fund in the hands of the American Petroleum Institute, which in turn sought the advice and co-operation of the National Research Council, this being a disinterested and well-organized scientific body, embracing all the natural sciences. The Central Petroleum Committee was then organized, consisting of twelve members, as follows: three members from each of the departments of Geology, Physics, and Chemistry of the National Research Council, and three representatives from the American Petroleum Institute. The personnel of this committee is as follows:

Physics: L. H. Adams, Geophysical Laboratory, Carnegie Institution of Washington; H. S. Taylor, professor of Physical Chemistry, Princeton University; R. A. Millikan, director of the Norman Bridge Laboratory of Physics, California Institute of Technology.

Chemistry: Benjamin T. Brooks, consulting chemist, 59 East 41st St., New York; William J. Hale, chairman of the Division, National Research Council; James F. Norris, professor of Organic Chemistry, Massachusetts Institute of Technology.

Geology: David White, chairman of the Division, National Research Council; K. C. Heald, geologist, Gulf Oil Corporation, Pittsburgh; E. DeGolyer, consulting geologist, 65 Broadway, New York.

American Petroleum Institute: R. L. Welch, general secretary; R. P. Anderson, technologist; Van H. Manning, former research director, American Petroleum Institute.

Dr. James F. Norris was designated as chairman, and Dr. William J. Hale as secretary.

Various researches have been organized in the fields of the three sciences, funds being allotted approximately equally. Representatives of each science submit to the Central Petroleum Committee an outline of the several projects proposed, with a budget estimate covering one year. Those accepted by the Central Committee are then passed on to the American Petroleum Institute representatives for final ratification, after which the supervision and prosecution of each accepted project devolves upon advisory committees chosen from among specialists who are particularly interested in, or familiar with, the problem involved.

The point should be stressed that the fund administered by the American Petroleum Institute is specifically for the support of researches of a purely scientific character, as distinguished from researches which have an economic object in view. The latter class falls more properly within the province of company activity. The right of publication of results of research financed through the American Petroleum Institute, as well as the announcement of accepted projects and personnel, is reserved by the Institute, and this information will be promptly made available in their bulletins, of which three have been issued. These bulletins are dated June 30 and October 25, 1926, and March 31, 1927, and may be secured from the Institute upon request. In them is outlined all the work now in progress. It may be added, however, that the Institute has not as yet announced a policy covering publication of results.

NATIONAL RESEARCH COUNCIL

For the information of members a word may be in order regarding the organization and purpose of the National Research Council. This body was an outgrowth of the war and was sponsored by President Wilson as a war measure designed to effect a mobilization of scientific thought of the country.

The Council is housed in a new building at 21st and B Streets, Washington, facing the Mall. The headquarters of the National Academy of Sciences are in the same building.

The Council is composed of several separate organizations called divisions, of which the Division of Geology and Geography is one unit. The several divisions are self-governing and elect their own officers for a period of one year. The chairman of the Division of Geology and Geography for the past two years has been David White, and the vice-chairman is Isaiah Bowman, both of whose terms of office expire April 30, 1927. The chairman is ineligible for re-election more than once. An executive committee of seven is in charge of current business. Members of the division are chosen by nine scientific societies, including the American Association of Petroleum Geologists, and there is also a limited number of members at large. The American Association of Petroleum Geologists is at present entitled to two members, who are appointed by the president for a period of three years. The present representatives are W. E. Wrather, whose term expires April 30, and W. H. Twenhofel. Sidney Powers has been appointed to succeed W. E. Wrather, and the latter becomes one of the members-at-large for a three-year term.

Each division has the privilege of appointing special committees for the furtherance of specific projects. Among these is a committee on Studies in Petroleum Geology composed of the following, all of whom are members of the Association: K. C. Heald, chair-

man; Carl H. Beal, E. DeGolyer, J. H. Gardner, F. H. Lahee, A. W. McCoy, W. Taylor Thom, Jr., Chester W. Washburne, David White, and W. E. Wrather. The personnel of this committee is practically the same as the research committee of the Association. Both committees have been co-operating with the geologists on the Central Petroleum Committee; but they are also working toward the furtherance of other research problems under separate endowments.

SUMMARY

It will be apparent from the foregoing that researches relating to geology, irrespective of the organization of committees, are in the hands of men of broad experience in the petroleum industry. It should be borne in mind that it is a legitimate enterprise for the Association as a separate entity to organize and promote any research it sees fit, independent of work done elsewhere. Further contributions of ideas, suggestions, and financial assistance are most heartily solicited. All petroleum geologists should be vitally interested in research. The multiple committees are merely the machinery to accumulate and put into operation the various ideas which originate with geologists working in the field. It is obviously impossible to approach more than a limited number by individual appeal, and unless an appeal of the present character is heeded it is evident that research work cannot be furthered on as comprehensive a scale as it deserves.

A specific example of the type of research which can be aided by each member of the Association is the symposium on the "Relation of Structure to Petroleum Accumulation" at the Tulsa Meeting, March, 1927. It is the desire of the Executive Committee of the Association that a careful analysis of the data relative to this subject be amassed, published in the *Bulletin* and in a separate volume, and critically studied by states, and then for the United States, by competent geologists who will volunteer their services. Such analyses should be of just as much value to the industry as laboratory experiments.

Many members were asked specifically to prepare descriptions of individual oil fields for this symposium. It was not possible to make separate appeals to all, nor is it too late to receive other contributions of papers to be incorporated in the symposium volume, which will be published later.

This type of research is within the reach of all. Will you help to make it a success? Contribution of ideas, of field observations, of valuable experience—information which costs no money, only a little calm reflection and time—is of vital importance.

This idea has been most difficult to inculcate in the minds of members, who seem to assume that research is merely a matter of raising money to be spent by a few interested and self-sacrificing individuals in university laboratories. Money can always be raised for meritorious purposes, but committees who are only human soon exhaust themselves of ideas. The impetus for new projects must come from studies and observations in the field.

W. E. WRATHER

DALLAS, TEXAS
April, 1927

ETHICS AND SOME OTHER THINGS

Ethics have been defined as being moral principles, quality, or practice. As the elements in this definition are dependent upon conceptions which are subject to variation induced by time, place, and custom, it follows that they vary; and, therefore, that ethics also vary. Among the more definite conclusions which can be arrived at is: that even

under the most excellent codes, ethics are to a large extent matters of individual interpretation.

It is perhaps upon the consultant that the burden of interpretation most often falls, for it is he who establishes direct contact with the layman. In the course of his work he finds that the accepted codes are generalized, and that the finer points of justice are left to his discretion; or, as we commonly say, his conscience. Complications are frequently present. For instance: a prospective client enters the office of a consultant and unequivocally offers him a lucrative commission. Perhaps the rent of the consultant is due, and he has dependents. The work appears to be both honest and personally profitable, and the fee means little to the visitor. From his experience and training, however, the consultant has reasons to believe that the work will not result in benefit to the client. Therefore, while he does not refuse the commission, preliminary to accepting it he informs his visitor of the various factors, and of the indicated result. The visitor now sees the situation in a new light. He remarks that he will consider the matter—which means never—and departs, leaving the consultant in a silent and a lonely office. It is complications such as this that arise when we approach absolute justice.

The disappointments attending a practice of ethics increase our ability to understand the problems of others. This is especially true with regard to aiding the inexperienced and the struggling in the professions; those who have not yet established a working balance between the ideal and the practical, or who strive under difficulties to combine ethics and the obtaining of sustenance.

It is the higher aspects of ethics, which embrace kindness shown the less fortunate by those who have made a portion of the grade, of which the writer would in particular speak. The consultant is fitted by experience to assume a prominent rôle in this respect. He is equaled or surpassed, however, by some executives; especially those who have gone first through his own crucible and then to the corporations. The extremes are perhaps found in the institutions of learning, for the instructor has ever a difficult position. If he is inefficient, his duties become routine and he loses the personal touch. In dealing with inferiors who never question his opinions he falls into the rut of self-complacency and conceived superiority. It is otherwise with the talent which coexists in our schools and universities. In the presence of the infinite complexity of the universe, a LeConte or an Osler is humble; and the wealth of his genius is transmitted to students whose achievements and affection are monuments to his memory.

We are profoundly influenced by many men and women, who are all, in the broadest sense, our teachers. The debts are passed on from generation to generation, not only among the lowly, but among the immortals the luster of whose names is undimmed by time. Behind Aristotle stands the shadow of Plato; and behind Plato, that of Socrates. Few of us will reach the heights, but achievement is relative, and an infinite understanding might rate all accomplishment from similar purposes the same.

If the preferred codes are strict, they at least honor the men that keep them; and the struggling youngster will meet; sooner or later, with many kindnesses. A tired old man, to whose opinion the scientific world defers, identifies his samples for him. His manuscripts are corrected by men of experience who listen gravely to his childish theories, and in the professional offices of the great corporations he is received with every mark of respect. These persons observe a meticulous care to admit him upon a plane of equality. And if he is not entirely without understanding, he will realize that in doing this they are paying homage to the one thing in which he is an equal: and that is ethics.

Ethical conduct goes down to basic principles which perhaps no man wholly comprehends, and its kindly effects are recorded with the finer things of life. It is not the recollection of success that turns back the years, but memories of kindness and the frail hands of loved ones who are gone. It is not the things of triumph that we remember, but those which are nearer to tears.

Each person must travel very far alone. He attends a place of learning, and in an atmosphere of scholastic idealism is taught certain moral and material rudiments. He spreads his wings slowly at first, perhaps in some protected position; but in time he feels that he can stand unaided. In that wonderful fire of youth which passes never to return, he proclaims his high purpose, believing, in the confidence inspired by ignorance, that he has only to work hard and be honest, and success must soon crown his efforts. But the world passes him by. It does not understand him any more than he understands it. At every turn is a blank wall that he cannot scale, and through a gray pall the universe is seen as a sullen monster. There comes a time when there is no star, when the paths of life are stone, and when even the people upon the streets appear wooden-faced. He is bewildered, and he is very tired. The light that sustains him from within grows dim. While in this slough of despond, he sees others who are less scrupulous or who ask fewer questions enjoying the prosperity and success denied him. He knows that he has but to turn his hand and these things will be his. What stands between is an intangible something which has neither form nor substance; and whose very existence is dependent upon the workings of his own mind. And that something, we call ethics.

J. E. EATON

LOS ANGELES, CALIFORNIA
April 14, 1927

EMPLOYMENT SERVICE

The Association has on file at headquarters a list of names of Association members whose services are available for new full-time and consulting connections in both subordinate and experienced executive capacities.

Employers anticipating changes in the personnel of their office or field forces are invited to make use of this service. There is no charge.

Members seeking either employer or employee should indicate qualifications or requirements, on forms furnished upon request, to the American Association of Petroleum Geologists, Box 1852, Tulsa, Oklahoma.

AT HOME AND ABROAD

The Arkansas State Geological Survey, GEORGE C. BRANNER, state geologist, has been provided with funds to carry on a research program covering minerals, oil, gas, and soils. An increase of one mill in the severance tax will probably provide between $40,000 and $50,000 for this work.

K. H. CRANDALL, formerly of Amarillo, Texas, is now with The California Company at Colorado, Texas.

J. P. MCCULLOCH is located at Apartado 15, Ocaña, Colombia, S.A.

RAYMOND S. BLATCHLEY, consulting oil geologist, announces the opening of his office at 817 Roosevelt Building, Los Angeles, California.

JOHN L. RICH, of Ottawa, Kansas, addressed the Toronto branch of the Canadian Institute of Mining and Metallurgy and the Ontario Mining Association, April 21, on "Possibilities of Oil Recovery by Mining."

THOMAS L. HARRISON, of Denver, Colorado, has been working in the Mid-Continent region during the past few months.

DONALD C. BARTON, of Houston, Texas, has resigned his position with the Geophysical Research Corporation and has opened an office in Houston as consulting geophysicist.

FOREST R. REES is chief geologist for the Pierce Petroleum Company at Tulsa.

BILL WEED, of the Gulf Production Company, has been transferred from Laredo tc Tyler, Texas.

O. B. STAGGS is geologist for the Skelly Oil Company of Tulsa. Mr. Staggs has been working at Fort Stockton, Texas.

R. J. CULLEN has resigned from the Amerada Petroleum Corporation to accept a position as subsurface geologist for the Twin State Oil Company of Tulsa.

GRADY KIRBY, of the Gulf Production Company, has been working at Palestine, Texas.

W. VAN HOLST PELLEKAAN, representative of the Royal Dutch Shell Company in the United States, has moved to St. Louis, Missouri, where he will be assisted by R. E. SHUTT, who has been assistant to Angus McLeod, of the Roxana Petroleum Corporation in Dallas.

BELA HUBBARD, in charge of the geological work of the Standard Oil Company of New Jersey in Venezuela, has been investigating geophysical work in Houston.

J. V. HOWELL, geologist for the Marland Oil Company at Amarillo, is making an investigation of the oil possibilities of the Hudson Bay region, Canada.

GEORGE BEVIER is division geologist for the Pure Oil Company in Houston.

S. A. JUDSON, geologist for the Humphreys Corporation, is working in East Texas.

JOHN L. FERGUSON, of the Amerada Petroleum Corporation, has been transferred from Amarillo to Palestine, Texas.

T. E. WEIRICH is chief geologist for the Tidal Oil Company at Tulsa.

JOHN W. CLARK, geologist for the Amerada Petroleum Corporation, has been transferred to the Fort Worth, Texas, office from Cisco, Texas.

P. O. HOLLAND has been transferred from the Forth Worth office of the Amerada Petroleum Corporation to their Cisco office.

CHARLES N. GOULD, director of the Oklahoma Geological Survey, announces that Governor Henry S. Johnston has signed the bill appropriating $45,000 per year, for the work of the Survey during the coming biennium. It is planned to put several parties in the field during the coming summer and to issue reports on the work accomplished. These plans contemplate studies of the Simpson formation of the Arbuckle Mountains, which contains the "Wilcox" oil sand, by Charles E. Decker; a study on the zinc fields of Ottawa County, by Samuel Wiedman; studies of the Cretaceous of western Oklahoma, by Fred Bullard; studies of the Woodford-Sycamore-Caney beds, of Mississippian and Pennsylvanian age, in the Arbuckle and Ouachita Mountains, by C. L. Cooper; a study of the asphalt of the state, carried on in co-operation with the Experiment Station of the U. S. Bureau of Mines at Bartlesville; and a study of road materials in co-operation with the State Highway Commission.

ALEXANDER DEUSSEN was unable to take part in the petroleum geology course at the University of Texas on account of illness. His place was taken by WALLACE E. PRATT, who discussed "The Geologists in the Petroleum Industry," "Petroleum in Texas," and "Some Recent Developments in Salt-Dome Oil Fields of Texas."

MISS ALVA C. ELLISOR is consulting paleontologist for the Humble Oil and Refining Company at Houston, Texas. Miss Ellisor is devoting her time to research problems in stratigraphy.

VAN COURT WARREN, consulting geologist and valuation engineer and former associate of Harry R. Johnson, announces the removal of his office to 1025 L.A. Stock Exchange Building, Los Angeles, California.

H. J. MCLELLAN, of the Humble Oil and Refining Company, is working in East Texas.

G. D. STEVENS, assisted by W. H. MCLAUGHLIN, represents the Gulf Production Company at Tyler, Texas.

WALLACE C. THOMPSON, of the Sun Oil Company, is working in East Texas.

R. D. MCCLUER, consulting geologist at Corsicana, Tesas, is working in East Texas.

W. H. WHITTIER is geologist for the Roxana Petroleum Corporation at Abilene, Texas.

K. M. WILSON, of the Douglas Oil Company, is working in Central Texas.

G. MOSES KNEBEL, of the Humble Oil and Refining Company, is living at Palestine, Texas.

SIDNEY PAIGE is working for the Amerada Petroleum Corporation in Tyler, Texas.

W. C. KINKEL, of the Mid-Kansas Oil Company, is working at Fort Stockton, Texas.

E. B. STILES, of the Humphreys Corporation, is working at Fort Stockton, Texas.

O. A. DISNEY is geologist for the Vacuum Oil Company in the Cisco district, Texas.

J. B. CARSEY, division geologist for the Humble Oil and Refining Company in West Texas, has moved from San Angelo to McCamey.

R. T. LYONS is district manager for the Skelly Oil Company at San Angelo, Texas.

W. E. HUBBARD is district manager for the Humble Oil and Refining Company at Amarillo.

FRED B. ELY has resigned from the Standard Oil Company of New Jersey and opened an office as consulting geologist at Room 1117, 135 Broadway, New York City.

O. C. HARPER has resigned from the Gulf Production Company to become a member of the Galt-Brown Oil Company, with headquarters at Midland, Texas.

EARL HUMMEL is associated with Gibson and Johnson in the Alexander Building, Abilene, Texas.

PAUL HUNTER, of the Marland Oil Company of Texas, has been transferred from Fort Worth to Abilene.

W. TAYLOR THOM, JR., will publish his notes on the "Geology of Fuels" used in lectures at Princeton University.

H. SMITH CLARK represents the Sinclair Oil and Gas Company at Abilene, Texas.

WALT M. SMALL has left Tampico permanently and will engage in consulting work in Texas.

ED OWEN is geologist for the Wentz Oil Corporation, at Cisco, Texas.

CHARLES JACQUA, of the Gulf Production Company, is working at Palestine, Texas.

P. W. MCFARLAND, of the Sun Oil Company, has been transferred from Laredo to Tyler, Texas.

C. N. HOUSH, of the Gulf Production Company, has been transferred from Laredo to Tyler, Texas.

MISS GLADYS HAWLEY, of Tulsa, went to Hinckley, Illinois, early in May, to be with her mother, who is recovering from a serious illness.

E. L. FIPPS, formerly with the Mid-Continent Petroleum Corporation, at Tulsa, has accepted a position with the Gypsy Oil Company, at Shawnee, Oklahoma.

STUART ST. CLAIR, of 25 Broadway, New York City, has been spending several weeks investigating conditions in the Mid-Continent region.

MARION H. FUNK is resident geologist for Trinidad Oil Fields Operating Company Ltd., Box 18, San Fernando, Trinidad, B.W.I.

NOAH C. ADAMS, geologist and independent operator, died at Tulsa, Oklahoma, April 18.

DOUGLAS B. STERRETT has resigned from the Pioneer Petroleum Company in Tulsa and is temporarily situated in Washington, D.C.

GROVER C. POTTER, chief geologist for the McMan oil and Gas Company of Tulsa, has been supervising geological work for his company in the San Angelo district.

C. B. TAYLOR, recently with the Sinclair Oil and Gas Company, is now associated with Wright and Doub, at Abilene, Texas.

HAROLD S. CAVE was stationed at Roswell, New Mexico, last month, for the Gypsy Oil Company.

J. VOLNEY LEWIS is employed by the Venezuelan Gulf Oil Corporation in a consulting capacity.

PROFESSOR ALAN M. BATEMAN, of Yale University, is spending the summer in Alaska.

KIRK BRYAN, of the U. S. Geological Survey, has received an appointment as assistant professor of geology at Harvard University.

A. H. GARNER, of New York City, is in Venezuela.

C. P. WATSON has resigned from the Amerada Petroleum Corporation to organize a royalty company in Fort Worth, Texas.

RALPH H. RICHARDS, of the Standard Oil Company of New Jersey, spent April in Washington. He has returned to South America.

LEON RUSS has resigned from the Texas Unity Oil Company.

L. G. DONNELLY, of the Maracaibo Oil Exploration Company, spent May in Venezuela.

RALPH SOPER, of the Pan American Petroleum Company, at Tampico, visited New York in May.

The Jno. W. Choate Interests have recently opened offices at Coleman, Texas, with HOWARD SAMUELL as chief geologist in charge of operations in Texas.

K. F. MATHER has received an appointment as professor of geology at Harvard University.

EVERETTE L. DEGOLYER, president of the Geological Research Corporation, lectured on "Geophysical Methods of Prospecting" before the May meeting of the New York section of the Mining and Metallurgical Society of America.

GEORGE C. BRANNER, state geologist of Arkansas, attended a meeting of the state geologists in Washington in April.

EUGENE STEBINGER, of the Standard Oil Company of New Jersey, spent May in the United States. He has been in charge of their work in Argentina for several years.

SYDNEY H. BALL, of New York City, returned from Chile in April.

FRED GARNJOST has accepted a position with The Texas Company, at Bayonne, New Jersey.

C. R. SCHROYER is in Venezuela.

E. L. ESTABROOK, of the Pan American Petroleum Company, has been in Venezuela.

JAMES L. DARNELL, engineer, removed his offices April 18 to the Graybar Building, 420 Lexington Avenue, New York City.

W. P. JENNY, geophysicist of Houston, has been at Pestalozzistr. 6, Berne, Switzerland, a few months, constructing special machines for the automatic computing of the land effect upon torsion balances.

J. P. BUWALDA has been appointed professor of geology and head of the department of geology at the California Institute of Technology, Pasadena.

W. H. TWENHOFEL and SIDNEY POWERS attended the meeting of the division of geology and geography of the National Research Council in Washington on April 30, as representatives of this Association. Other members who attended were K. C. HEALD, W. A. NELSON, DAVID WHITE, E. DEGOLYER, GEORGE OTIS SMITH, ALFRED C. LANE, W. C. MENDENHALL, J. A. CUSHMAN, W. P. WOODRING, P. D. TRASK, R. C. MOORE, and CHESTER W. WASHBURNE.

A new geological map of British Honduras is being prepared by MR. OWER, formerly government geologist of British Honduras, for publication in England. The government survey has been discontinued.

RAYMOND C. MOORE will resume his work as head of the department of geology at the University of Kansas.

WILLIAM A. HUDSON, formerly with the Gulf Production Company, is associated with Buckley Brothers, at Eastland, Texas.

H. D. EASTON made the location for the discovery gas well in the Amory area of Mississippi. Mr. Easton maintains his consulting headquarters in the Ardis Building, Shreveport, Louisiana.

H. B. PATTON, formerly of Stamford, Texas, has moved to 3111 West 36th Ave., Denver, Colorado.

A. C. NOÉ, of the University of Chicago, left May 11 for a five months' stay in the Donetz Basin of Russia, as a member of a commission organized by the Allen & Garcia Company, consulting engineers, 21 East Van Buren St., Chicago. The purpose of this commission is to locate and design large coal mines in the Donetz Basin for the Soviet government.

EARL A. TRAGER, associated with Earl Oliver and Company, of Ponca City, Oklahoma, spent much of the past spring in southeastern New Mexico and southwestern Texas.

F. JULIUS FOHS, consulting geologist, 51 East 42d St., New York, is giving a course of lectures on oil geology at Columbia University.

CHESTER A. THOMAS has accepted a position as head of the geological and land departments for the Skelly Oil Company, at El Dorado, Kansas.

EMERSON H. PARKS, of Denver, was working in the Mid-Continent in May.

W. A. THOMAS, of the Pure Oil Company, has been transferred from San Angelo, Texas, to Columbus, Ohio.

THOMAS C. HIESTAND is now with McBride, Inc., in the Wright Building, Tulsa.

GILBERT P. MOORE has gone to Venezuela with the Standard Oil Company. His address is Apartado 85, Maracaibo.

I. M. HAWKINS is now in the employ of the California Company, doing field work in the Fort Stockton area. His address is Box 846, Colorado, Texas.

A. D. BROKAW, of the firm of Brokaw, Dixon, Garner, & McKee, 120 Broadway, New York City, visited the Shreveport, Louisiana, district last month.

PARKER D. TRASK, research associate of the American Petroleum Institute, addressed the American Geophysical Union at Washington, D.C., last month. He announced an intensive study of actual conditions of oil formation in the bottom of the sea. The work is being carried on by a special committee. W. A. J. M. VAN DER GRACHT and T. WAYLAND VAUGHAN are members of this committee.

The West Texas Geological Society and the Bureau of Economic Geology of the University of Texas held jointly a geologic excursion and conference in the Delaware and Guadalupe Mountains of Texas and New Mexico on May 21 and 22.

CORRECTION

J. Y. SNYDER, consulting geologist, City Bank Building, Shreveport, a close observer of Louisiana geology, points out an error in an item on page 437 of the April *Bulletin*, referring to the Eocene–Lower Cretaceous contact unexpectedly found in a drilled well. The well is that of the Louisiana Petroleum Company in Sec. 22, T. 17 N., R. 6 E., Richland Parish. The evident unconformity is at 2,382 feet and the surface elevation is 75 feet.